US 20240319309A1

(19) **United States**

(12) **Patent Application Publication** (10) **Pub. No.: US 2024/0319309 A1**

BAO et al. (43) **Pub. Date: Sep. 26, 2024**

(54) **MEASUREMENT REPORT WITH MEASUREMENT INDICATIONS FOR MULTIPLE SUB-BANDS OF A REFERENCE SIGNAL FOR POSITIONING RESOURCE**

(71) Applicant: **QUALCOMM Incorporated**, San Diego, CA (US)

(72) Inventors: **Jingchao BAO**, San Diego, CA (US); **Sony AKKARAKARAN**, Poway, CA (US); **Tao LUO**, San Diego, CA (US); **Juan MONTOJO**, San Diego, CA (US); **Alexandros MANOLAKOS**, Escondido, CA (US)

(21) Appl. No.: **18/262,362**

(22) PCT Filed: **Feb. 3, 2022**

(86) PCT No.: **PCT/US22/70513**

§ 371 (c)(1),
(2) Date: **Jul. 20, 2023**

(30) **Foreign Application Priority Data**

Mar. 10, 2021 (GR) 20210100146

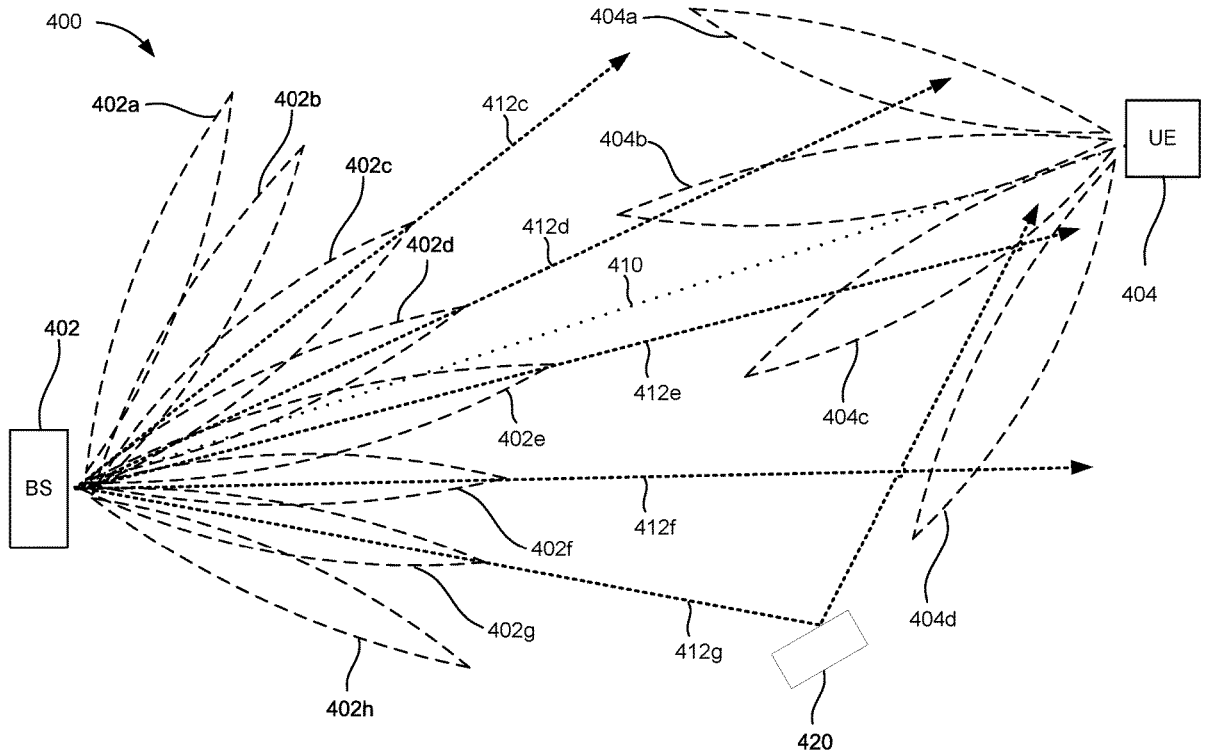
Publication Classification

(51) **Int. Cl.**
G01S 5/00 (2006.01)

(52) **U.S. Cl.**
CPC ***G01S 5/0036*** (2013.01)

(57) **ABSTRACT**

In an aspect, a wireless node performs measurements of an RS-P (e.g., PRS or SRS-P) on different sub-bands of an RS-P resource. The wireless node transmits separate indications of the measurements in a measurement report to a position estimation entity. The position estimation entity determines a positioning estimate of the UE based in part on the measurement report.



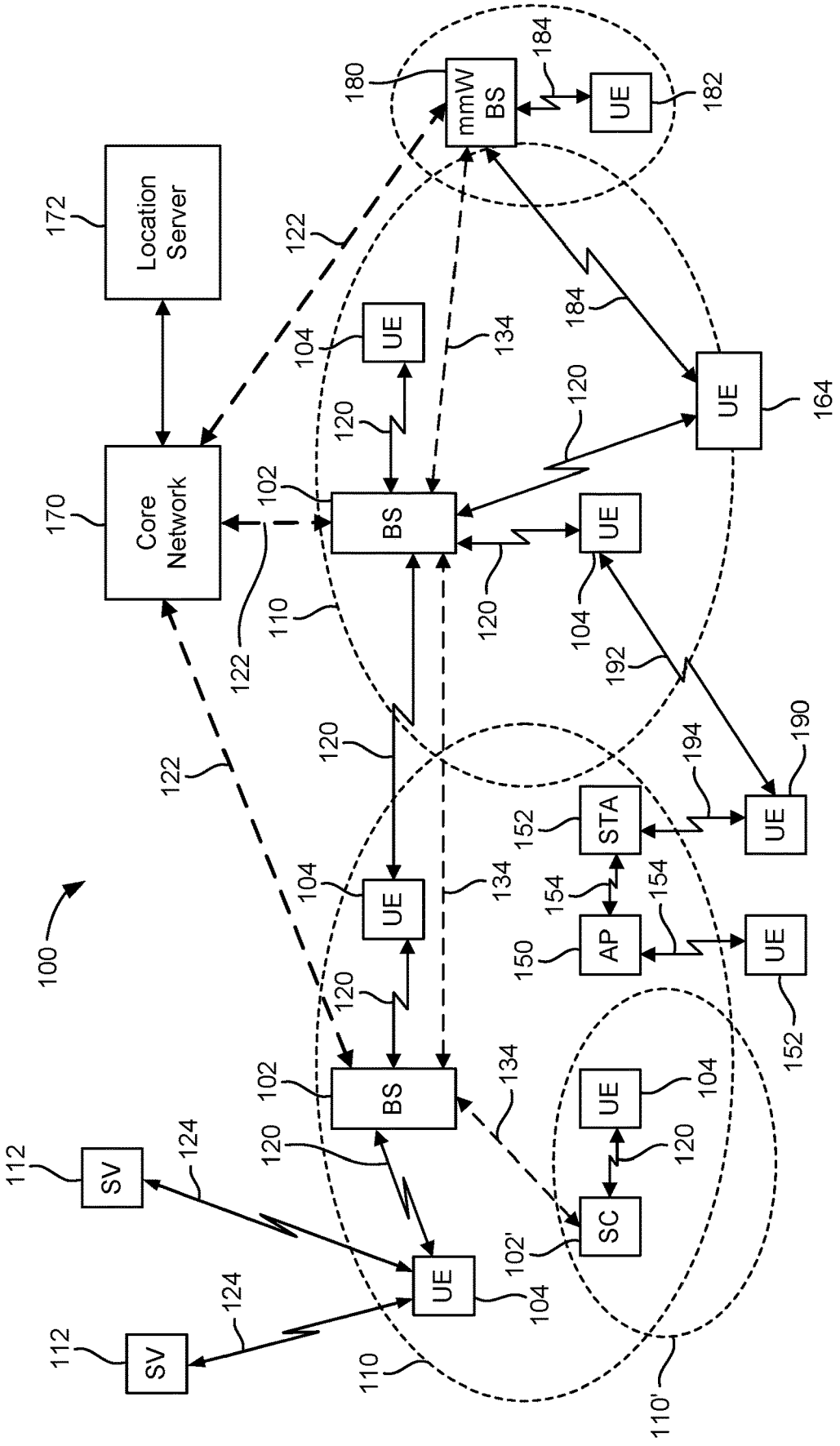

Location Server
172
Core Network
170
mmW BS
180
184
UE
182
122
104
134
120
164
102
BS
110
192
190
194
STA
152
154
AP
150
100
112
SV
124
102'
SC
110'

FIG. 1

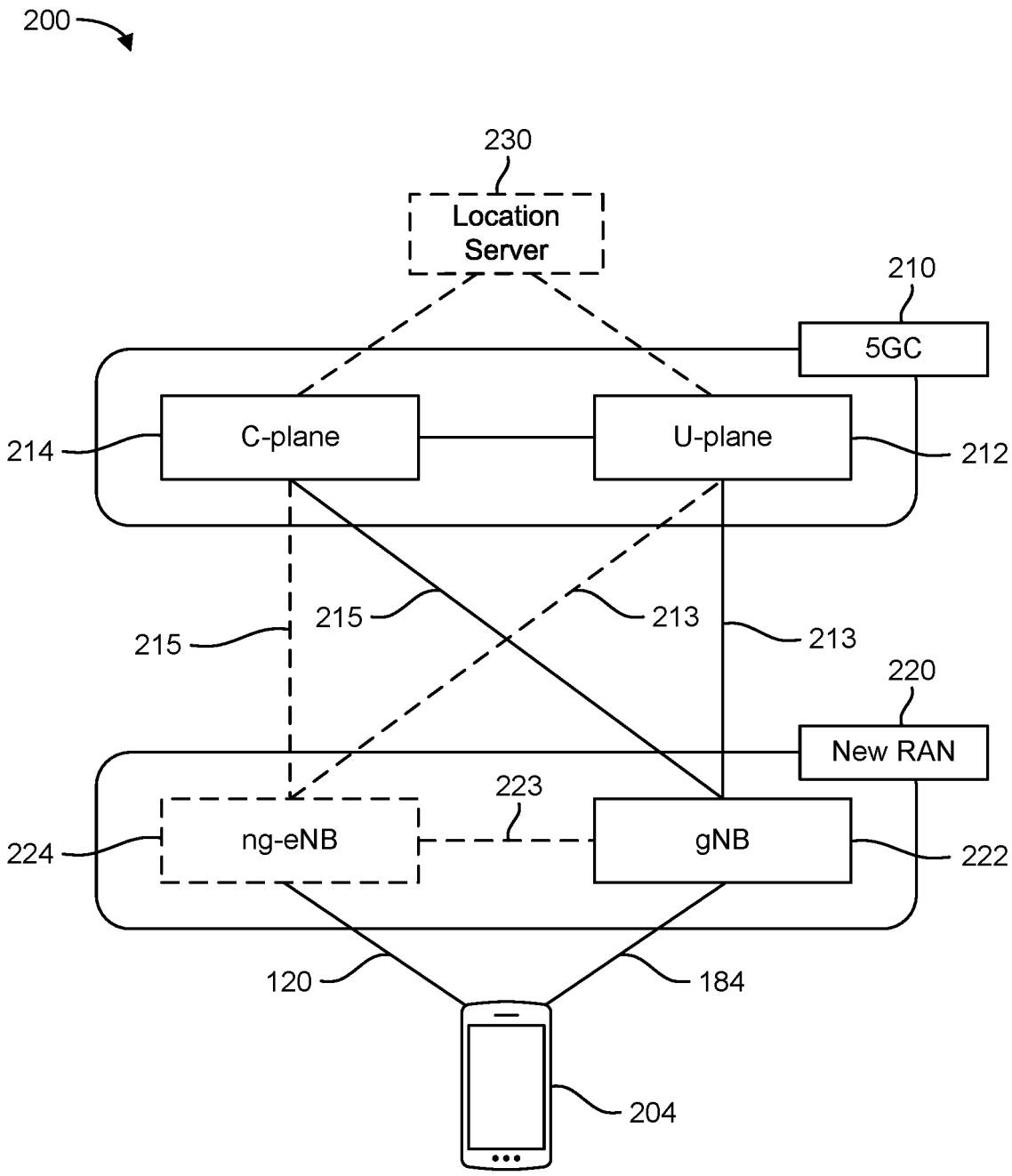

200
230
Location Server
210
5GC
214
C-plane
U-plane
212
215
215
213
213
220
New RAN
223
224
ng-eNB
gNB
222
120
184
204

FIG. 2A

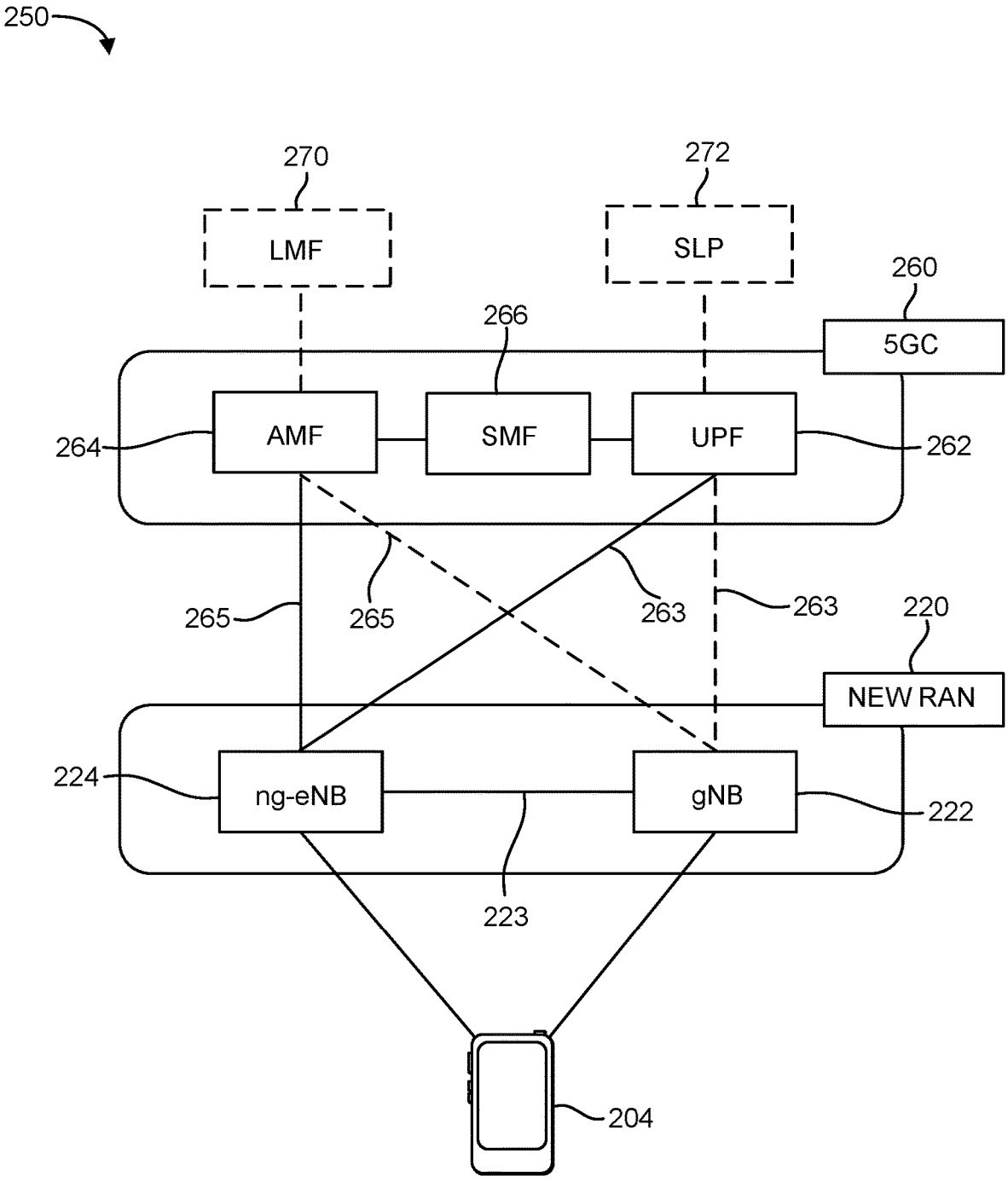

250
270
LMF
272
SLP
260
5GC
266
AMF
SMF
UPF
264
262
265
265
263
263
220
NEW RAN
224
ng-eNB
gNB
222
223
204

FIG. 2B

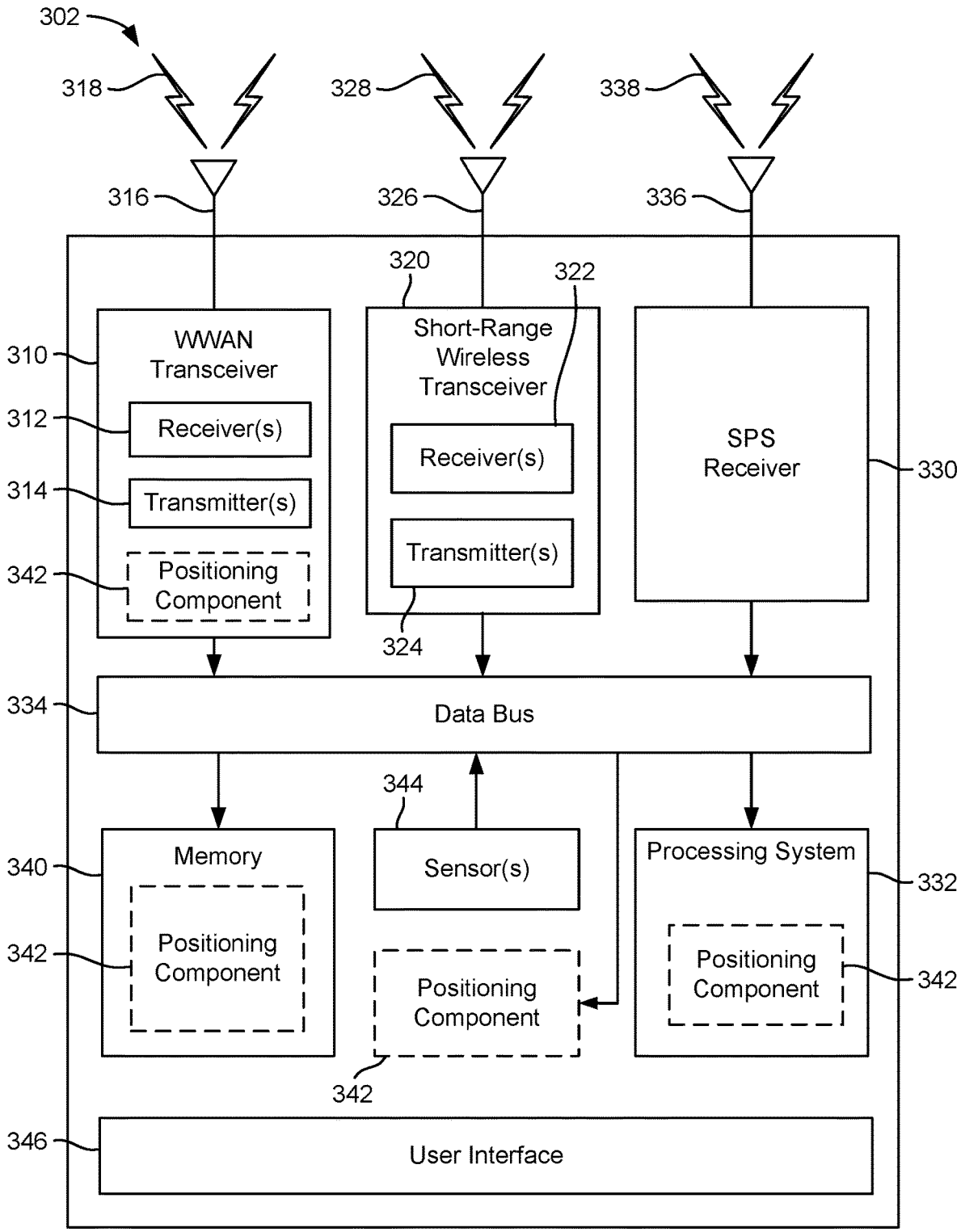

302
318
328
338
316
326
336
320
322
310
WWAN Transceiver
Short-Range Wireless Transceiver
312
Receiver(s)
Receiver(s)
SPS Receiver
330
314
Transmitter(s)
Transmitter(s)
342
Positioning Component
324
334
Data Bus
344
340
Memory
Sensor(s)
Processing System
332
342
Positioning Component
Positioning Component
342
Positioning Component
342
346
User Interface

FIG. 3A

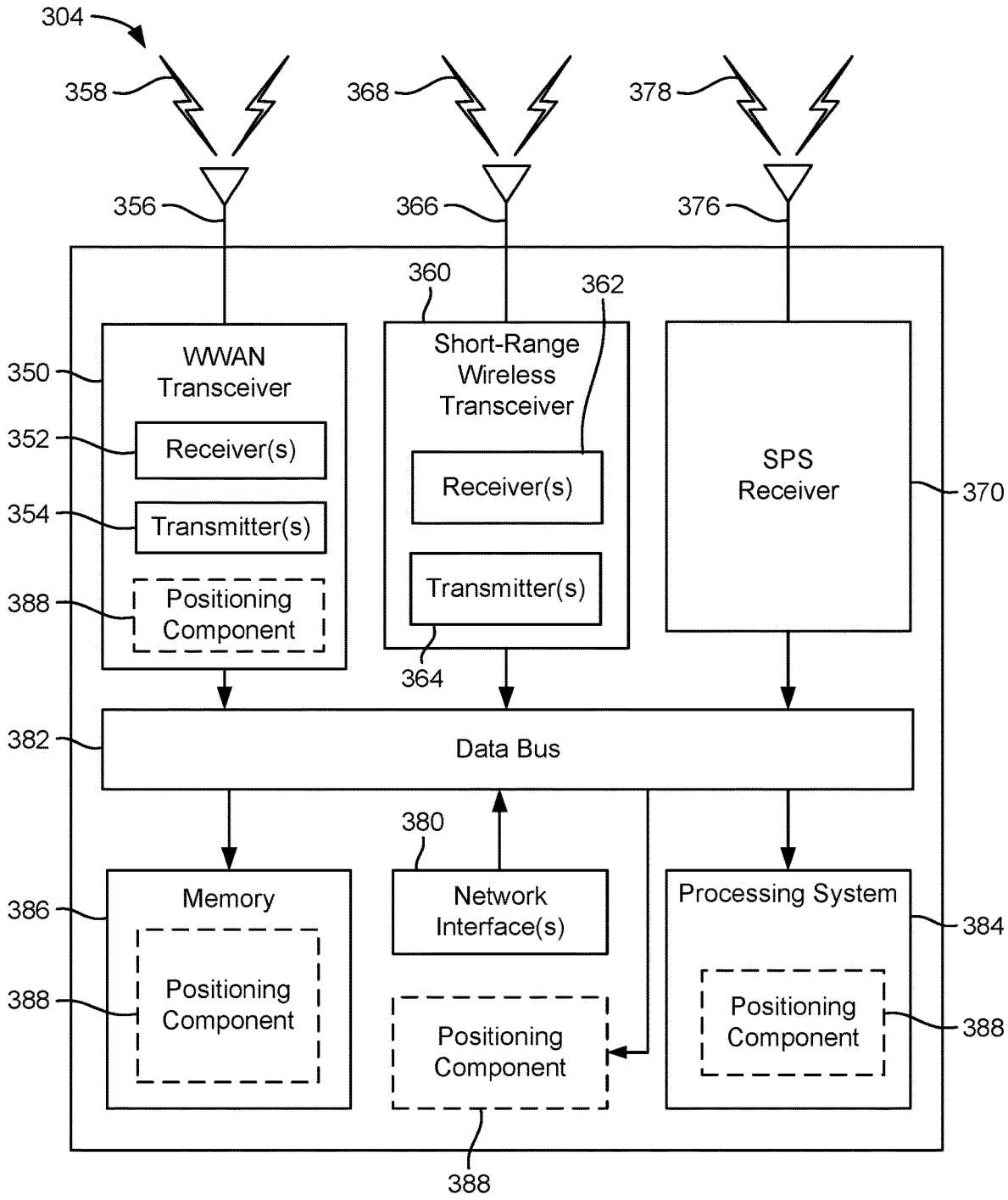

304
358
368
378
356
366
376
360
362
350
WWAN Transceiver
352
Receiver(s)
354
Transmitter(s)
388
Positioning Component
Short-Range Wireless Transceiver
Receiver(s)
Transmitter(s)
364
SPS Receiver
370
382
Data Bus
380
386
Memory
Positioning Component
388
Network Interface(s)
Positioning Component
388
Processing System
Positioning Component
384
388

FIG. 3B

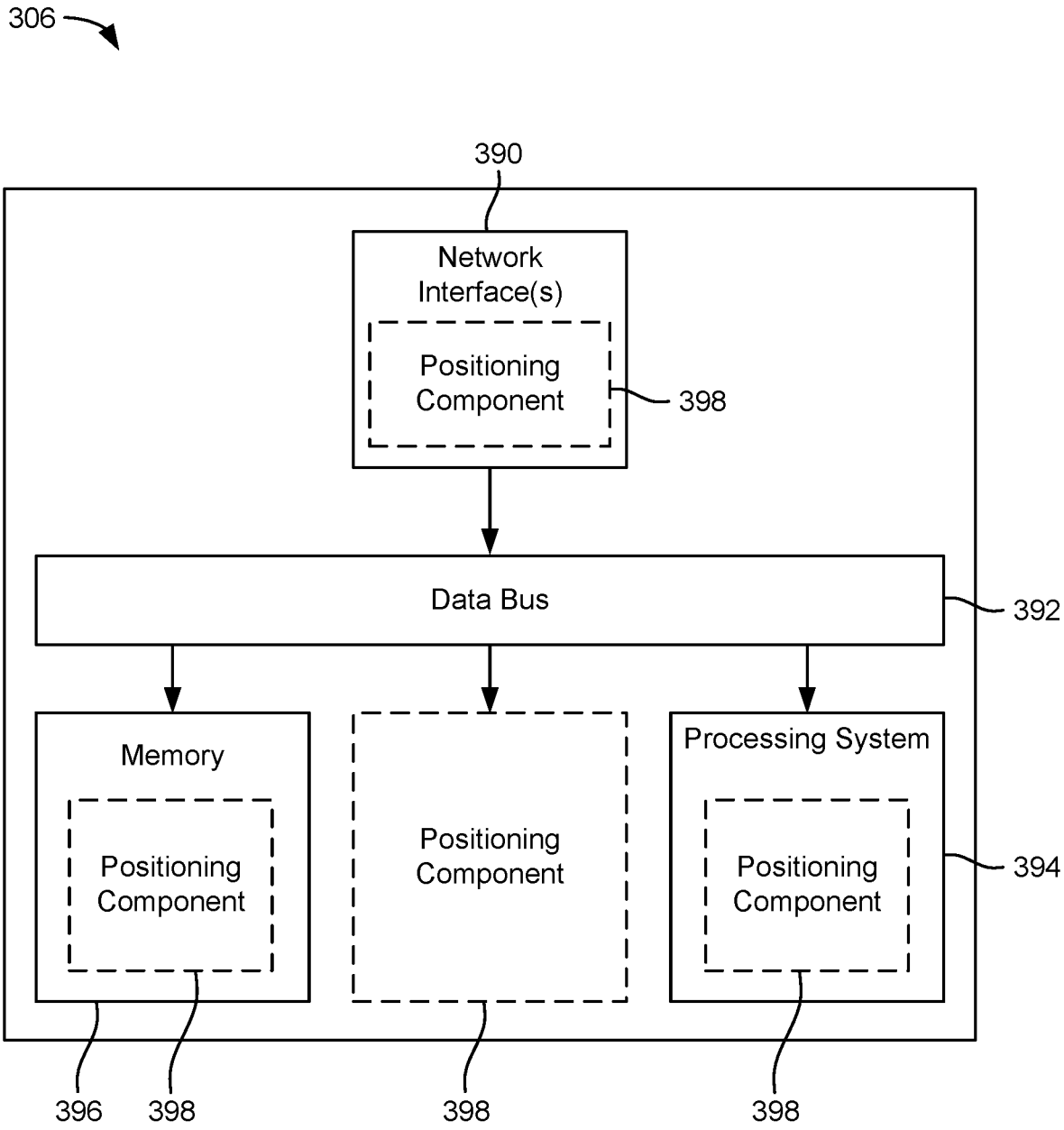

306
390
Network Interface(s)
Positioning Component
398
Data Bus
392
Memory
Positioning Component
Positioning Component
Processing System
Positioning Component
394
396
398
398
398

FIG. 3C

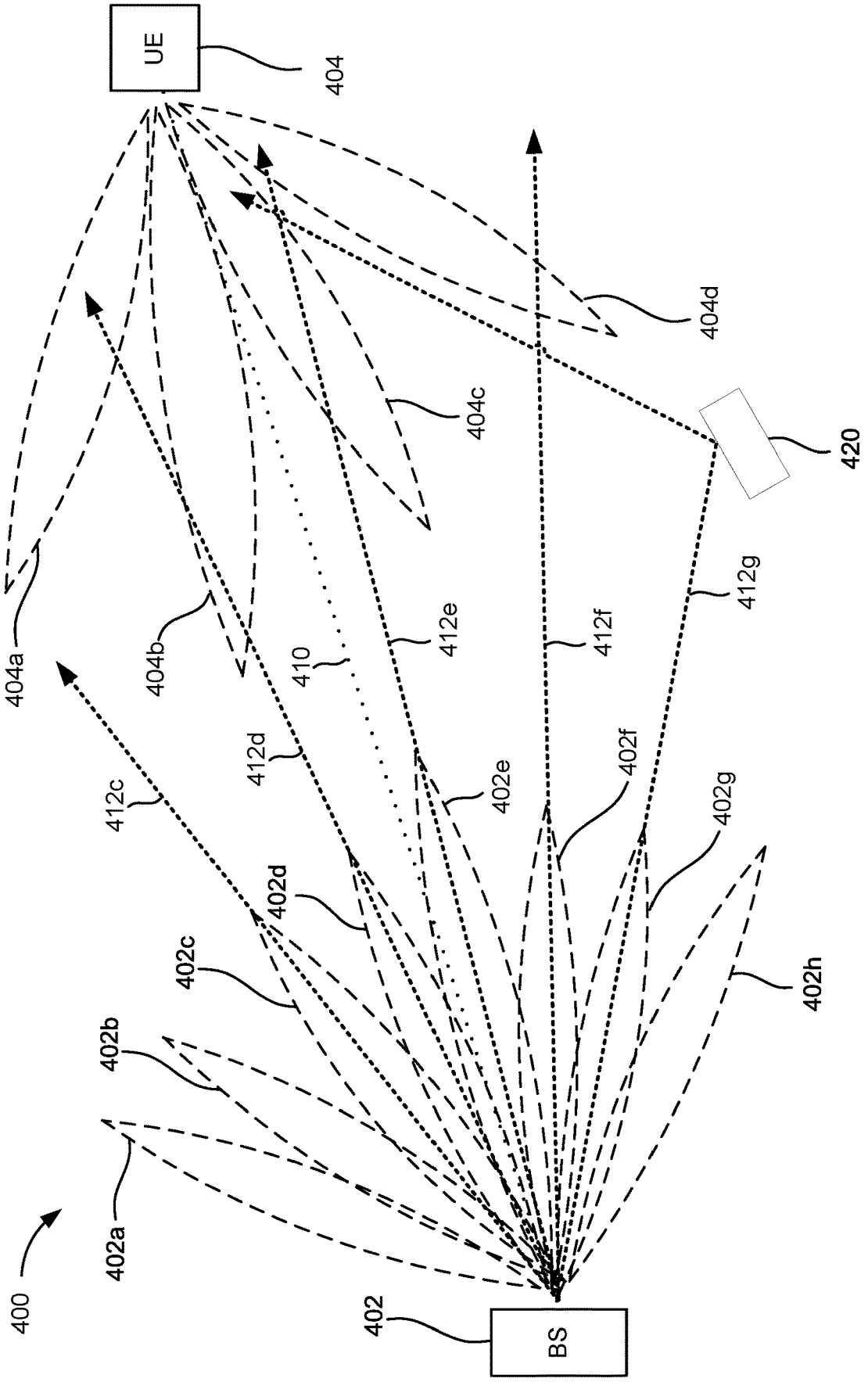

UE
404
404d
404c
420
404a
404b
410
412e
412f
412g
412d
412c
402e
402f
402g
402d
402c
402b
402h
402a
400
402
BS

FIG. 4

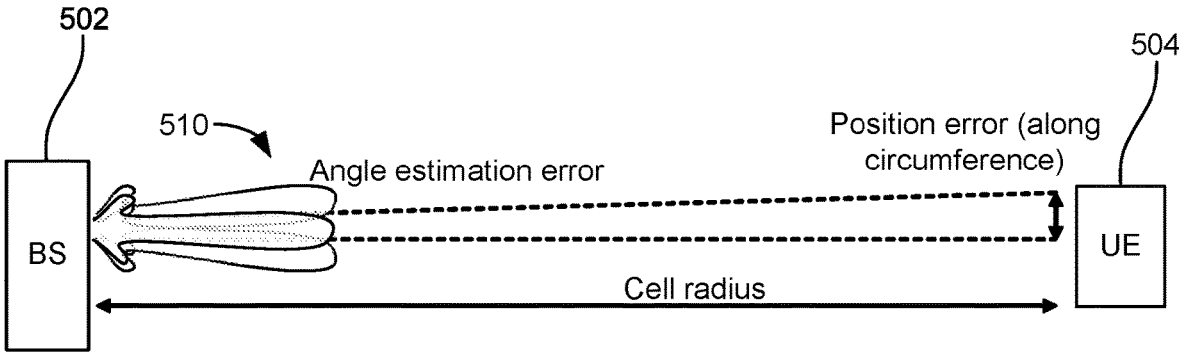

502
504
510
Angle estimation error
Position error (along circumference)
BS
UE
Cell radius

FIG. 5

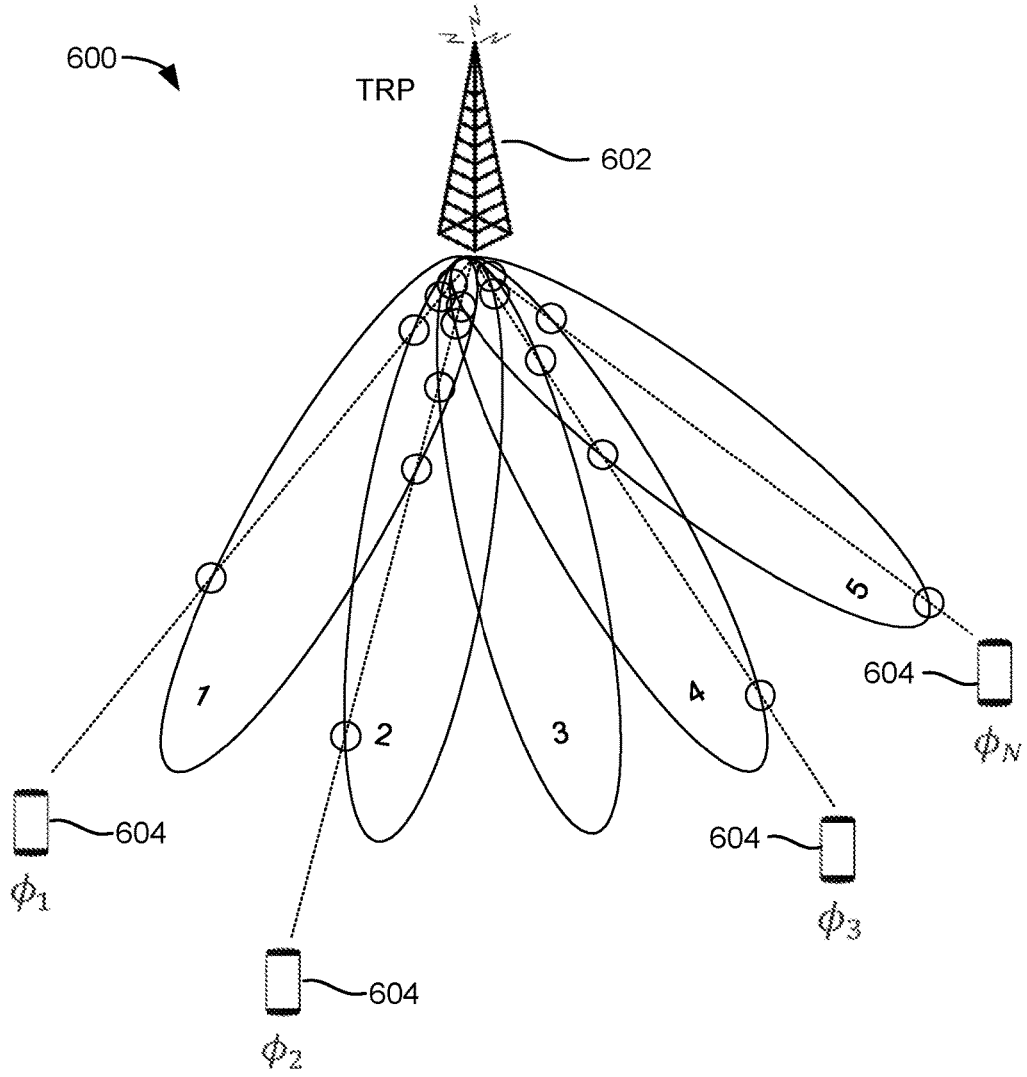

600
TRP
602
1
2
3
4
5
604
604
604
604
ϕ_1
ϕ_2
ϕ_3
ϕ_N

FIG. 6

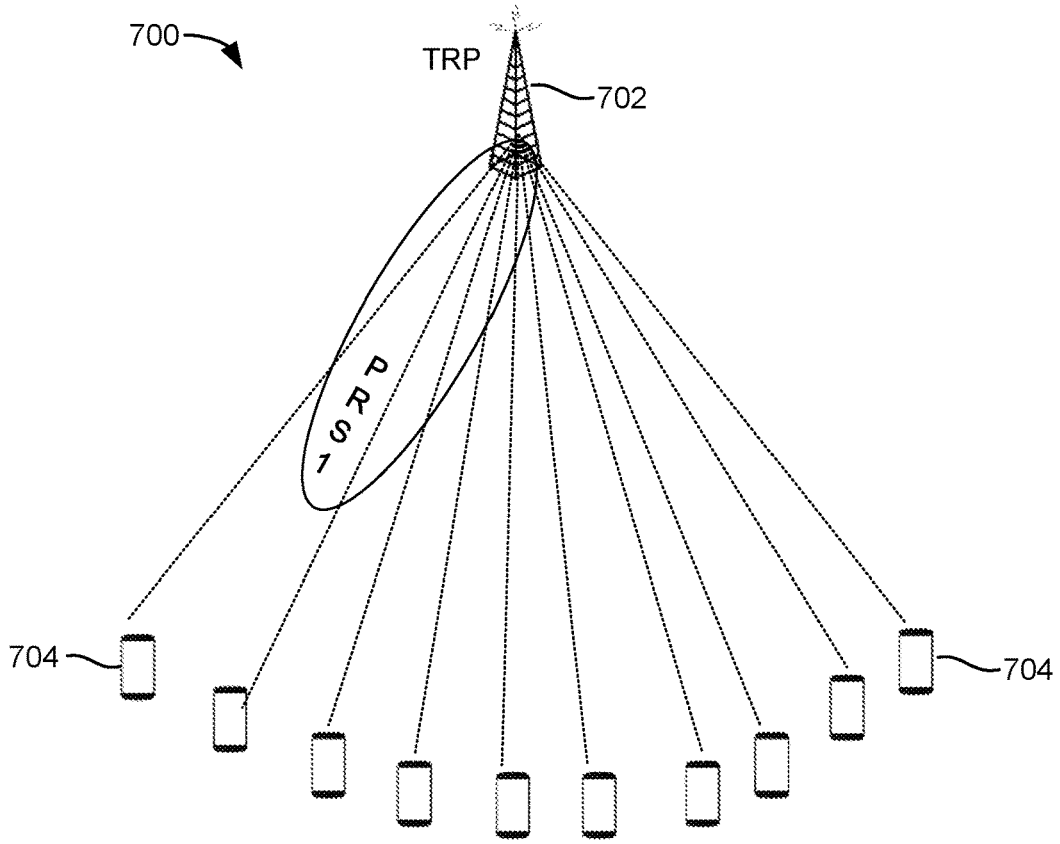

700
TRP
702
PRS1
704
704

FIG. 7

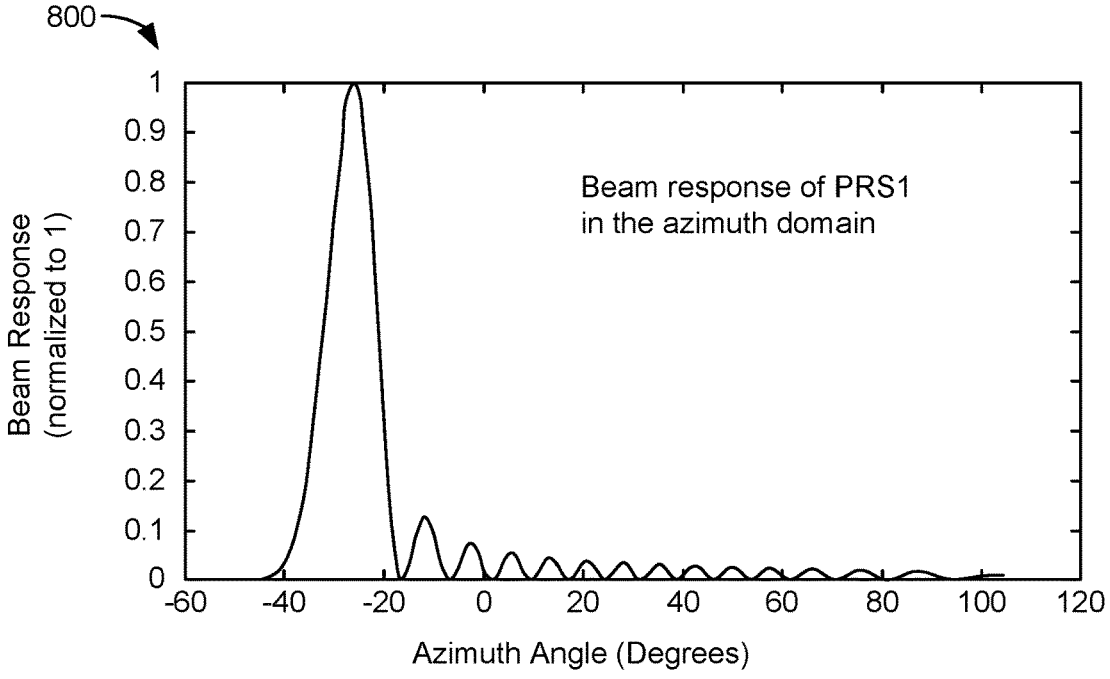

800
Beam Response (normalized to 1)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-60
-40
-20
0
20
40
60
80
100
120
Azimuth Angle (Degrees)
Beam response of PRS1
in the azimuth domain

FIG. 8

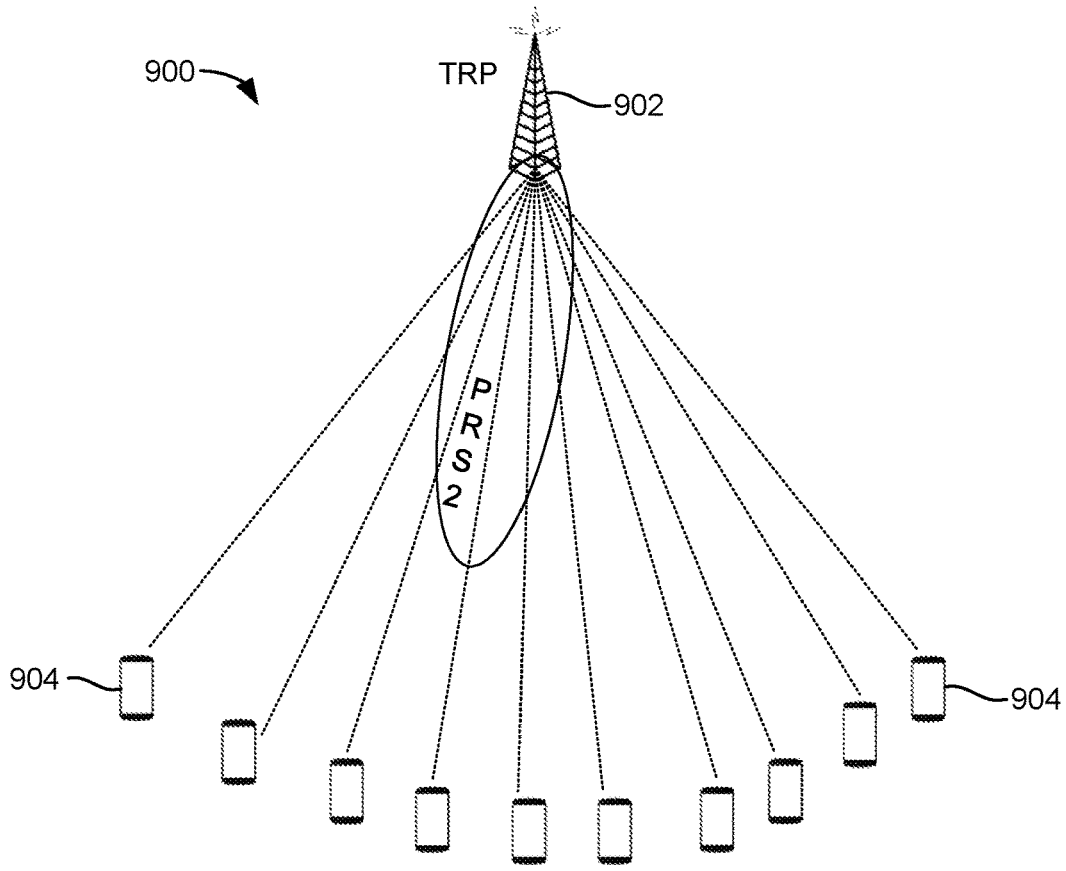

900
TRP
902
PRS2
904
904

FIG. 9

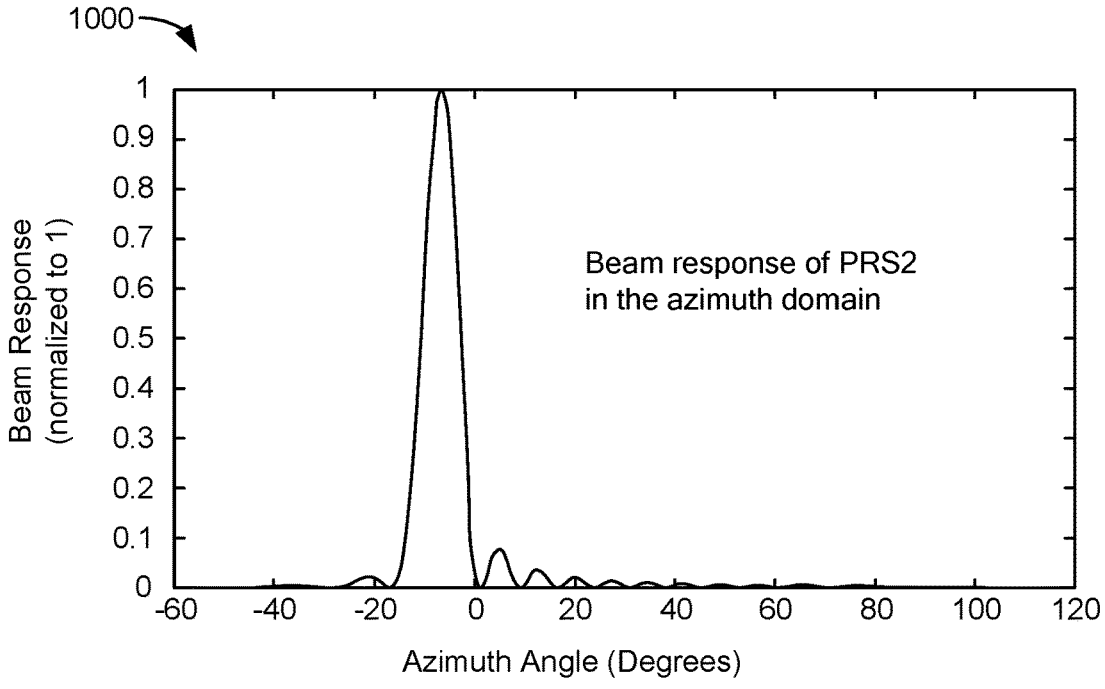

1000
Beam Response (normalized to 1)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-60
-40
-20
0
20
40
60
80
100
120
Azimuth Angle (Degrees)
Beam response of PRS2
in the azimuth domain

FIG. 10

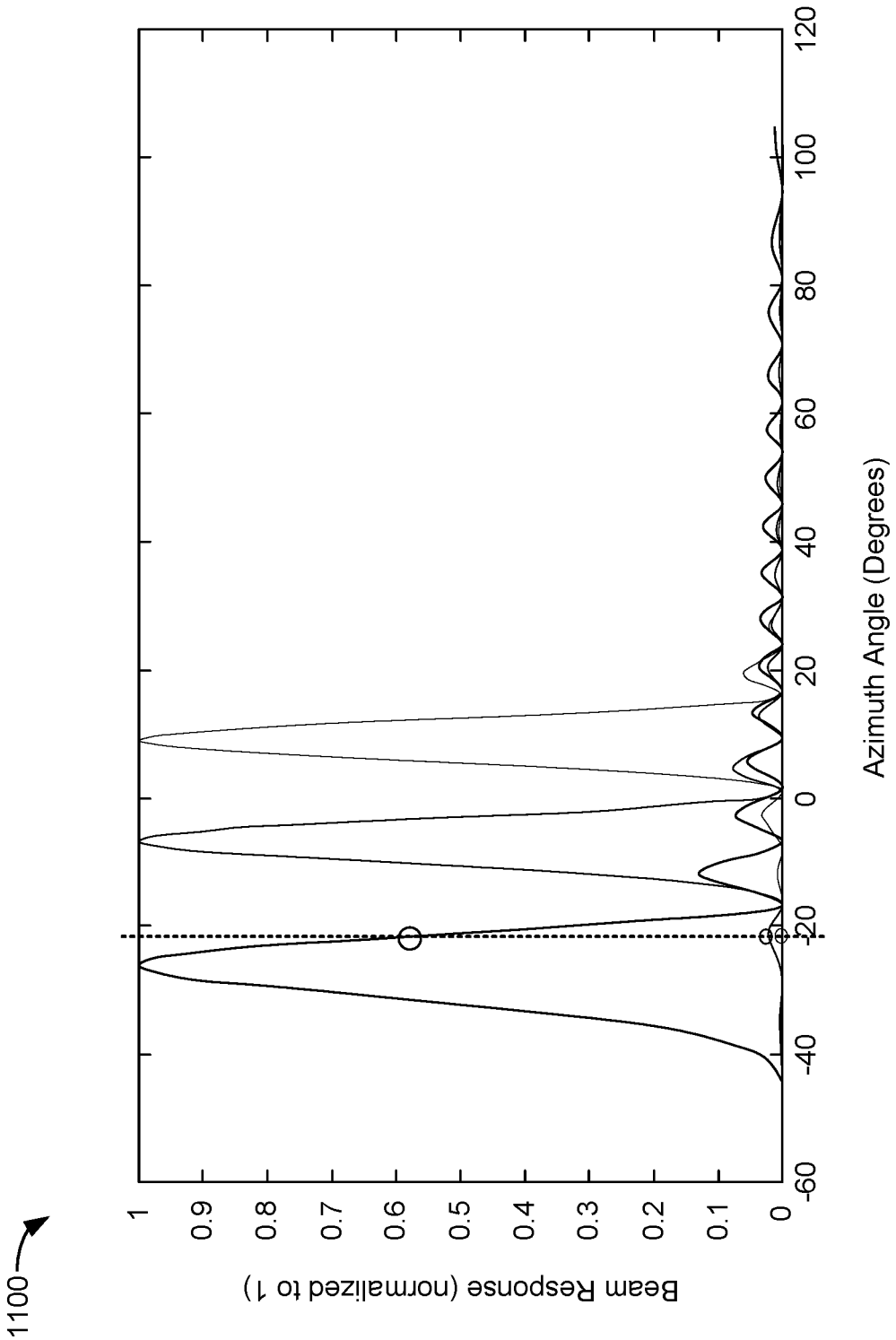

1100
Beam Response (normalized to 1)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-60
-40
-20
0
20
40
60
80
100
120
Azimuth Angle (Degrees)

FIG. 11

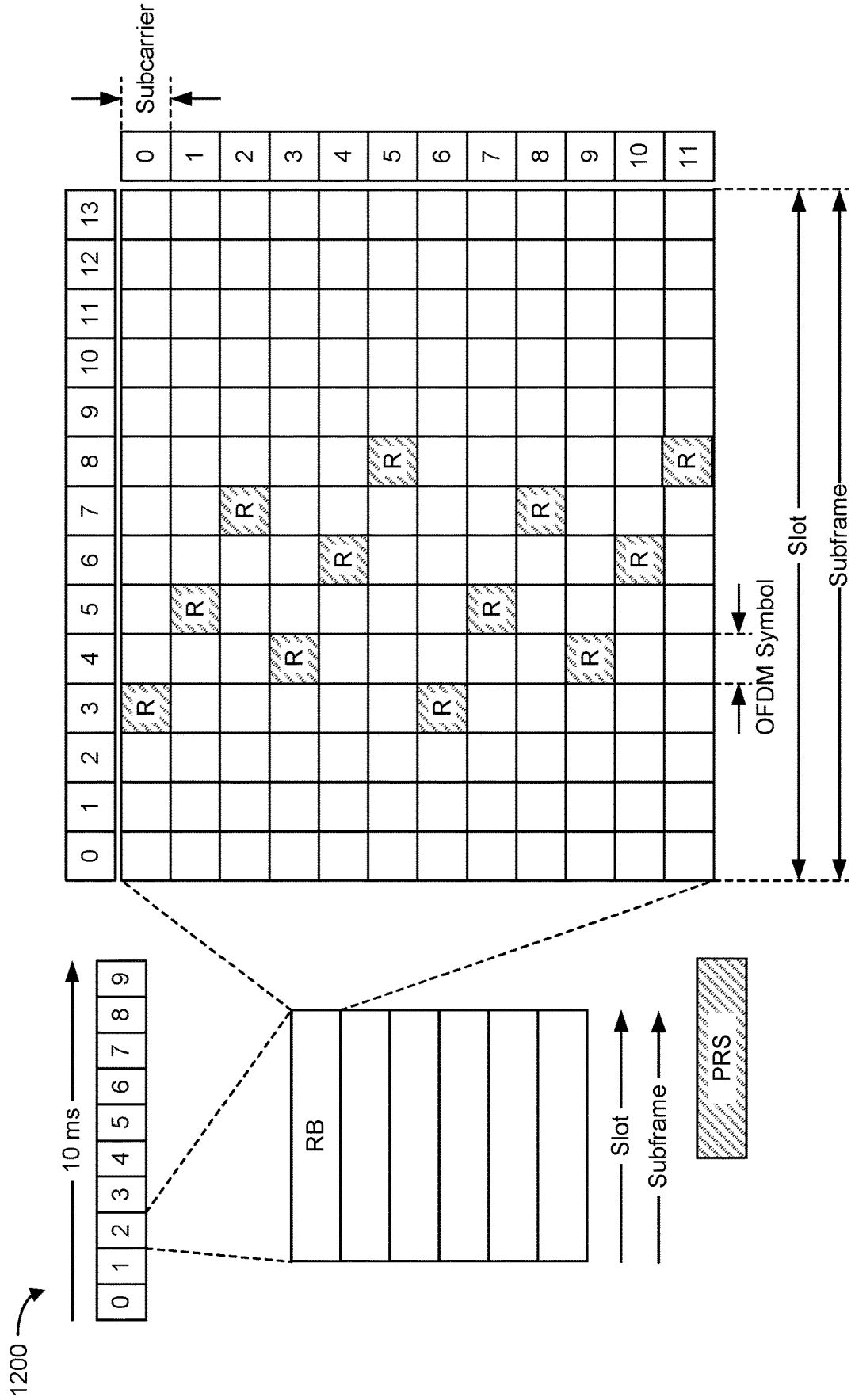

1200
10 ms
0 1 2 3 4 5 6 7 8 9
RB
Slot
Subframe
PRS
Subcarrier
0 1 2 3 4 5 6 7 8 9 10 11
0 1 2 3 4 5 6 7 8 9 10 11 12 13
R
OFDM Symbol
Slot
Subframe

FIG. 12A

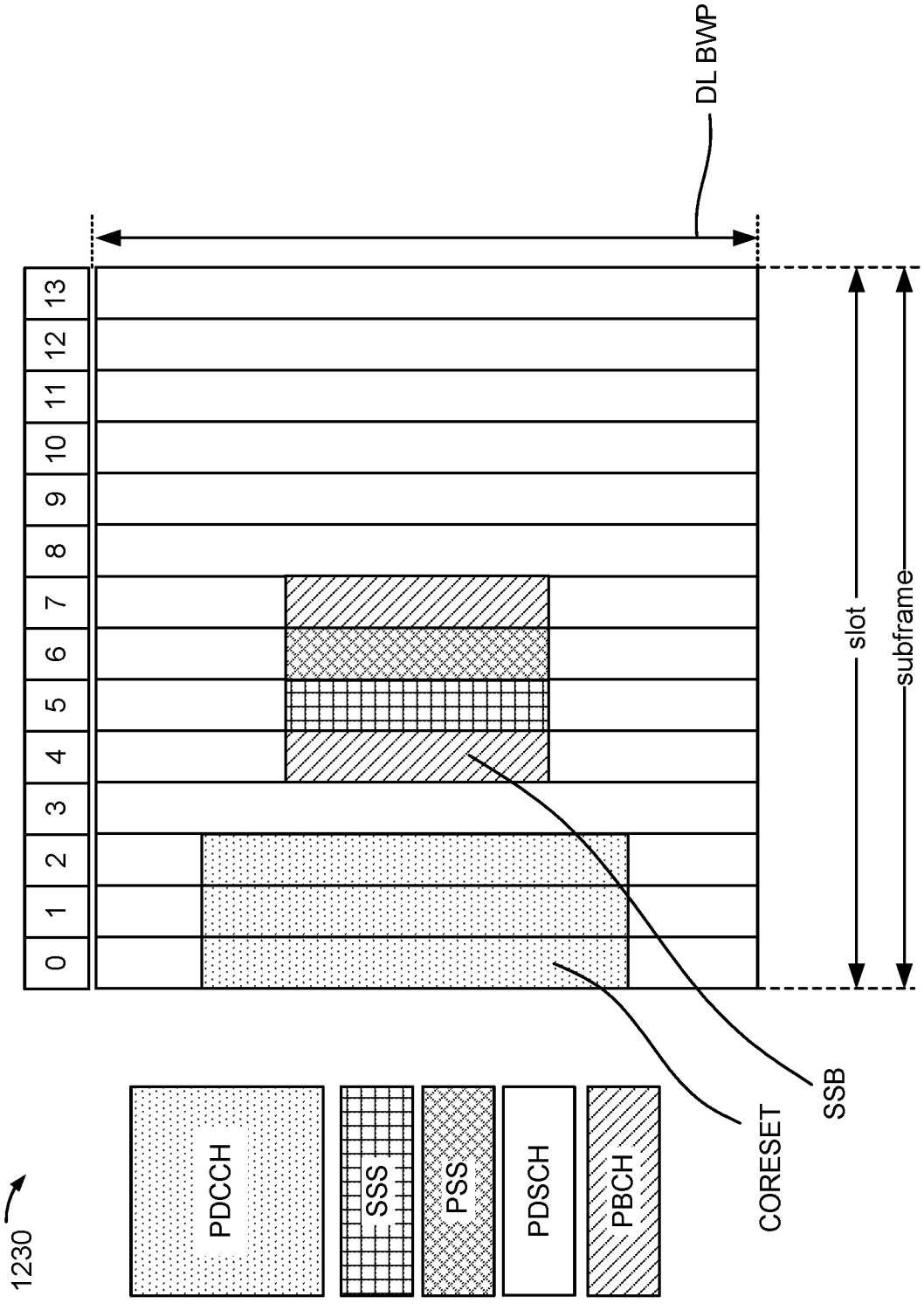

DL BWP
0
1
2
3
4
5
6
7
8
9
10
11
12
13
slot
subframe
SSB
CORESET
PDCCH
SSS
PSS
PDSCH
PBCH
1230

FIG. 12B

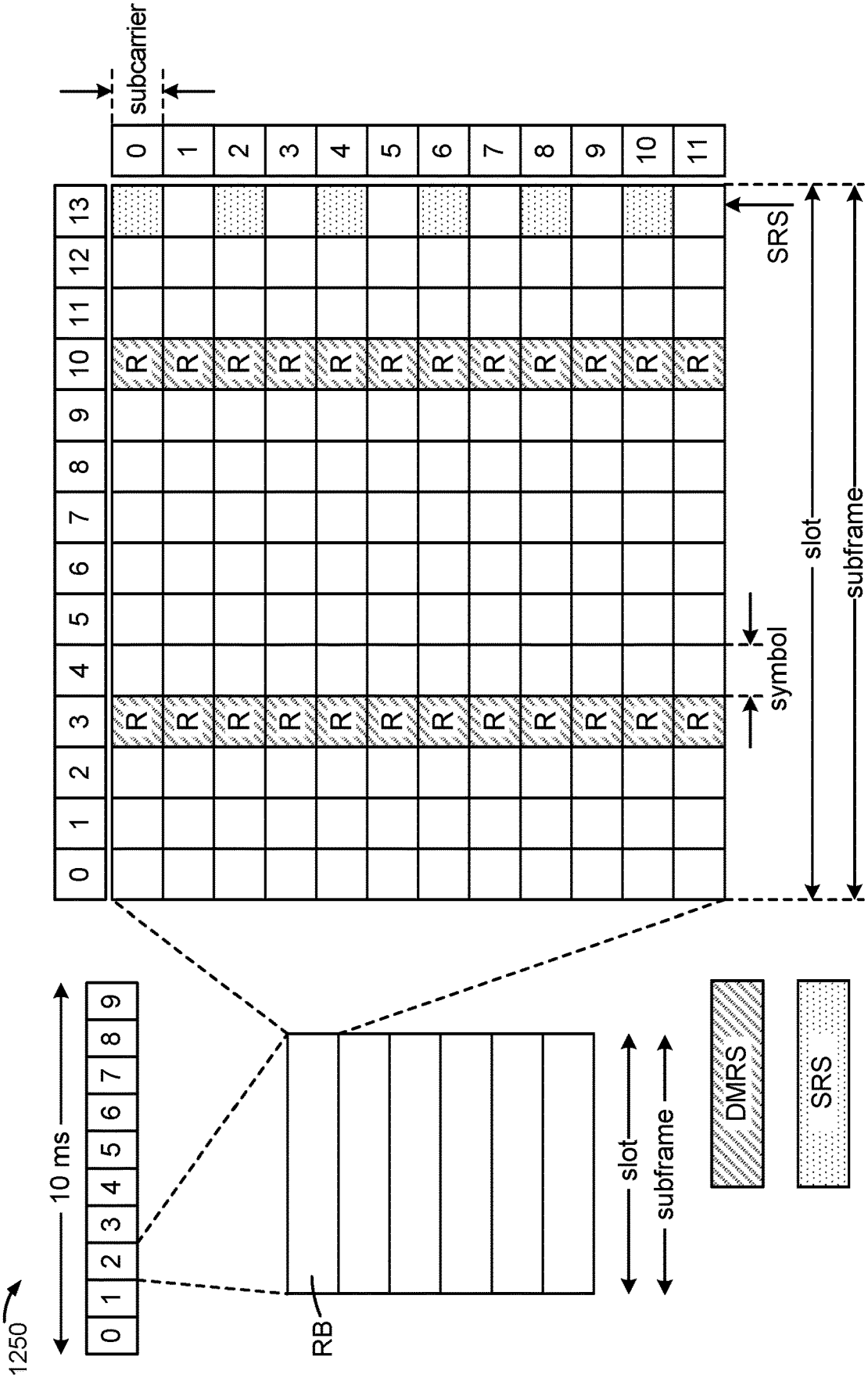

1250
0
1
2
3
4
5
6
7
8
9
10 ms
RB
slot
subframe
DMRS
SRS
subcarrier
0
1
2
3
4
5
6
7
8
9
10
11
12
13
R
symbol
slot
subframe
SRS

FIG. 12C

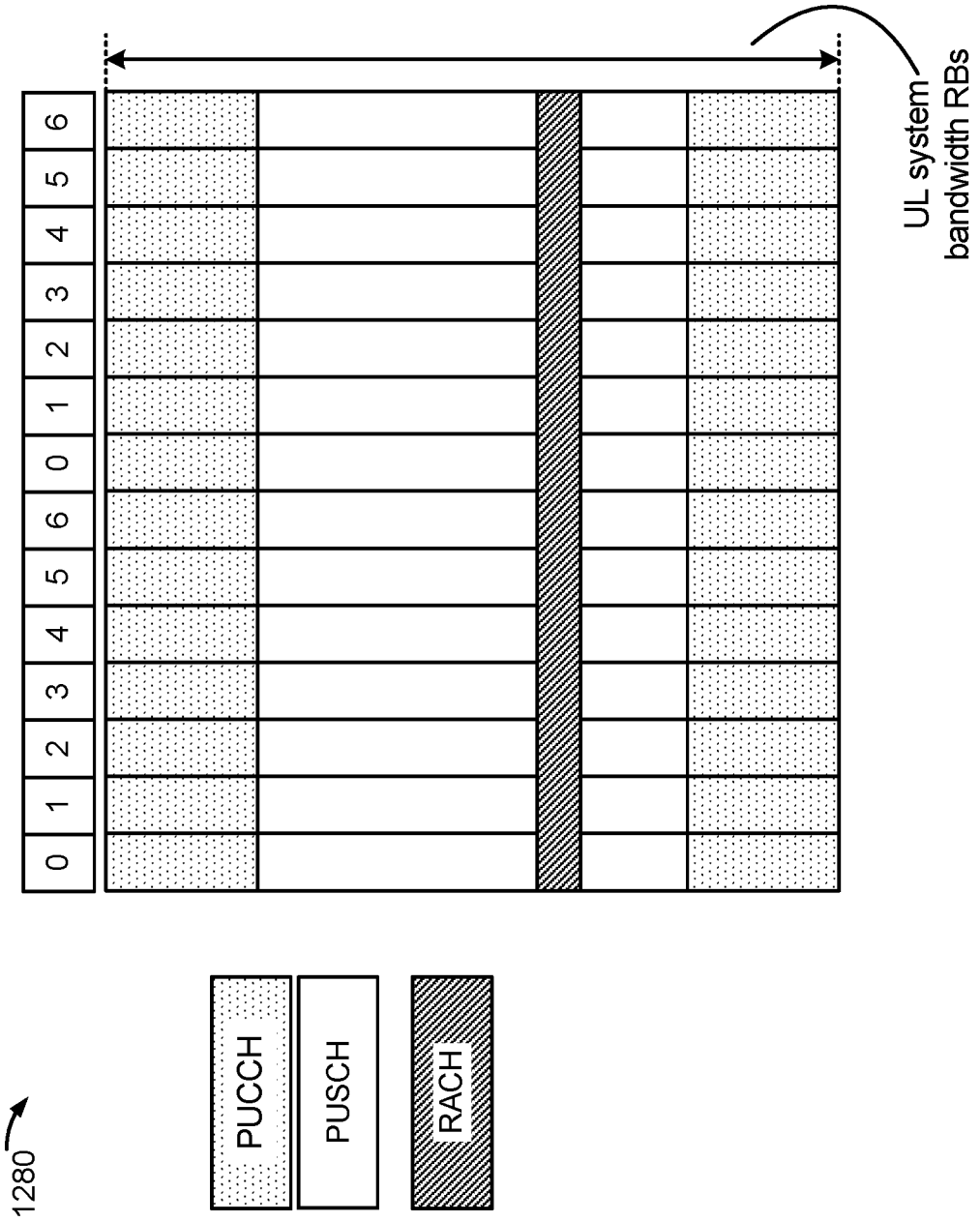

UL system bandwidth RBs
0 1 2 3 4 5 6 0 1 2 3 4 5 6
PUCCH
PUSCH
RACH
1280

FIG. 12D

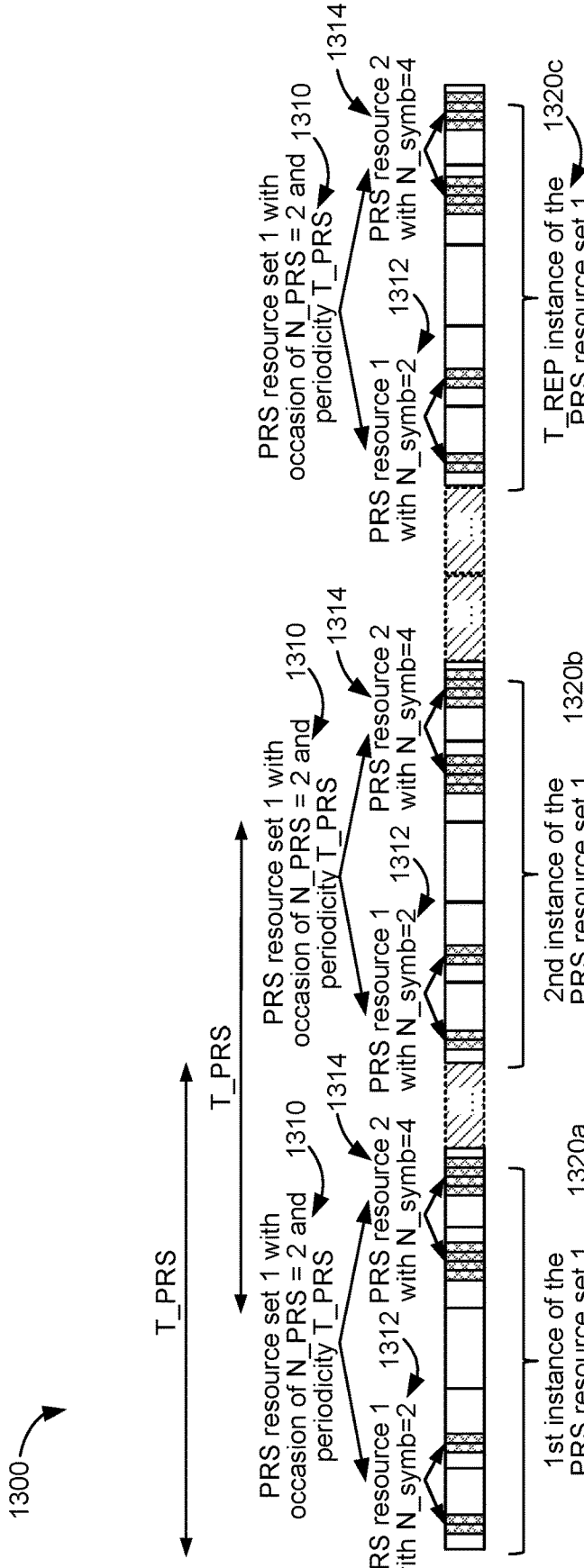

1300
T_PRS
T_PRS
PRS resource set 1 with occasion of N_PRS = 2 and periodicity T_PRS
1310
1314
PRS resource 1 with N_symb=2
1312
PRS resource 2 with N_symb=4
1320a
1st instance of the PRS resource set 1
2nd instance of the PRS resource set 1
1320b
T_REP instance of the PRS resource set 1
1320c

FIG. 13

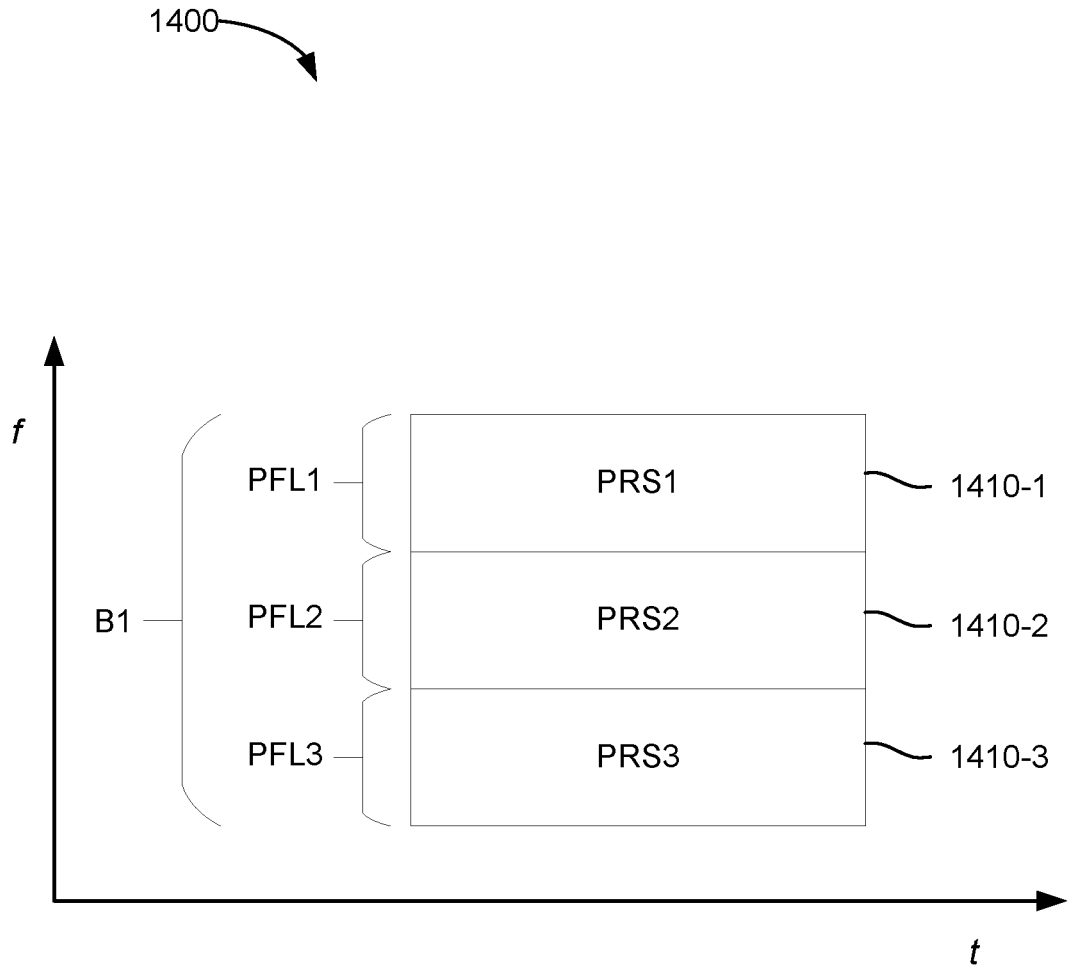


FIG. 14

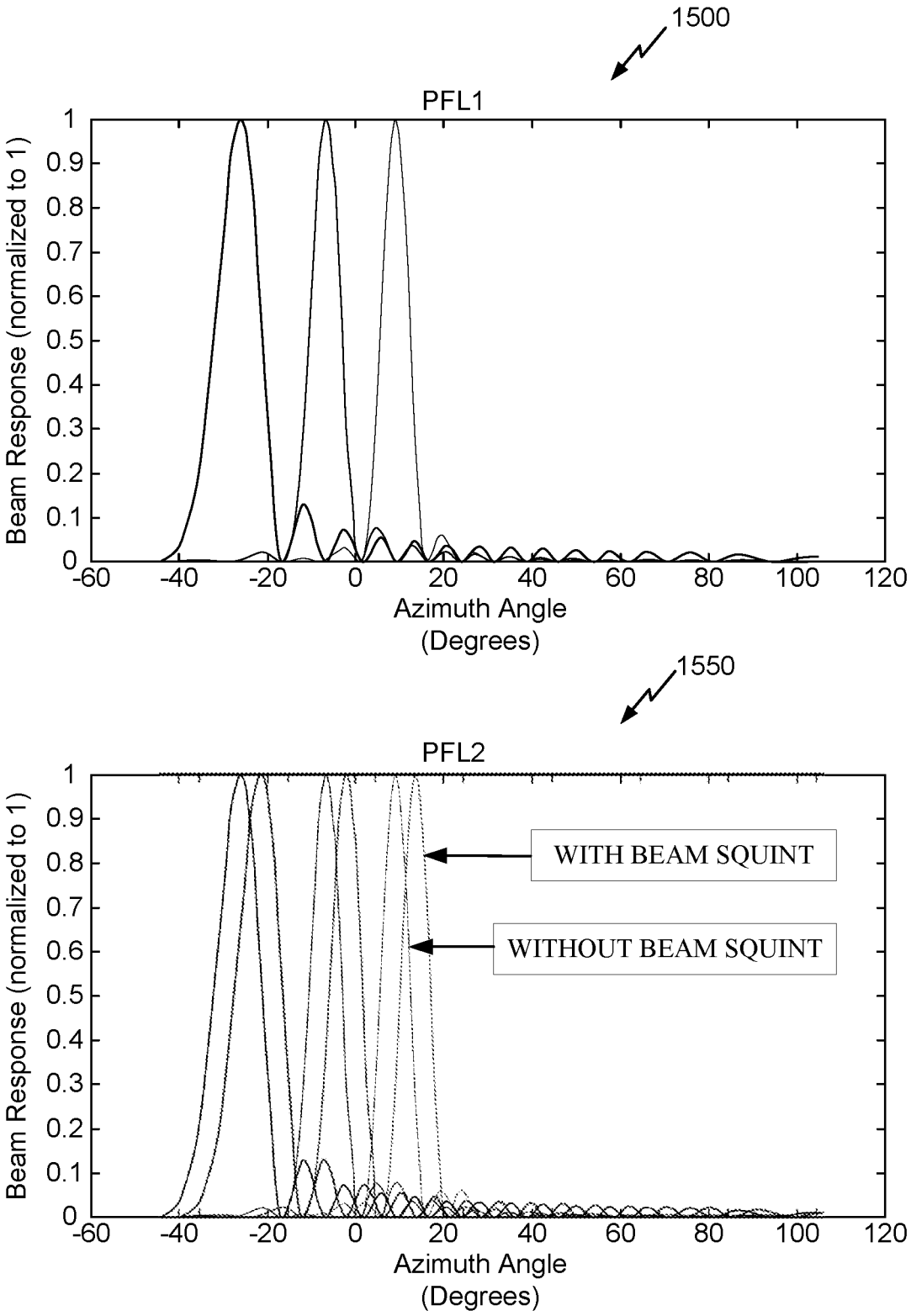

1500
PFL1
Beam Response (normalized to 1)
Azimuth Angle
(Degrees)
1550
PFL2
WITH BEAM SQUINT
WITHOUT BEAM SQUINT
Beam Response (normalized to 1)
Azimuth Angle
(Degrees)

FIG. 15

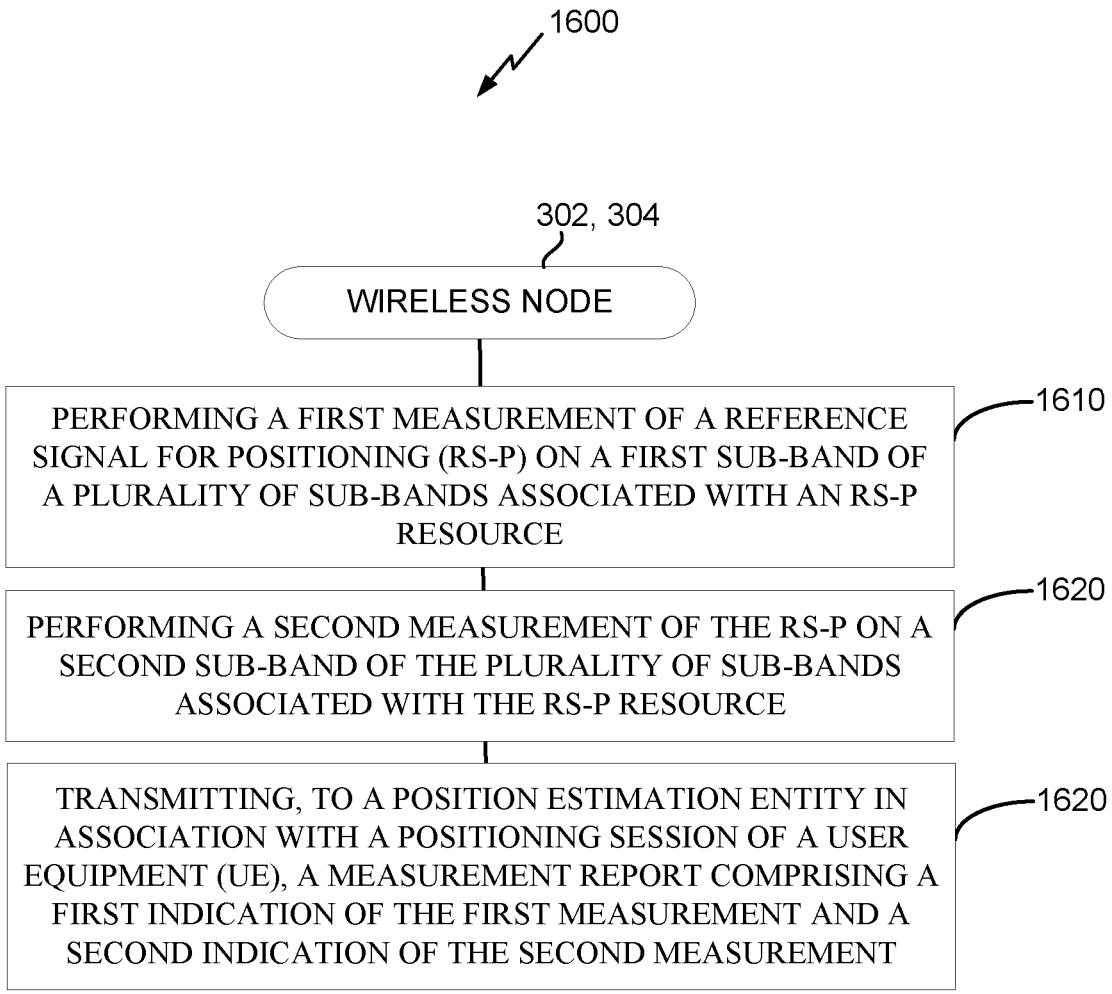

1600
302, 304
WIRELESS NODE
PERFORMING A FIRST MEASUREMENT OF A REFERENCE SIGNAL FOR POSITIONING (RS-P) ON A FIRST SUB-BAND OF A PLURALITY OF SUB-BANDS ASSOCIATED WITH AN RS-P RESOURCE
1610
PERFORMING A SECOND MEASUREMENT OF THE RS-P ON A SECOND SUB-BAND OF THE PLURALITY OF SUB-BANDS ASSOCIATED WITH THE RS-P RESOURCE
1620
TRANSMITTING, TO A POSITION ESTIMATION ENTITY IN ASSOCIATION WITH A POSITIONING SESSION OF A USER EQUIPMENT (UE), A MEASUREMENT REPORT COMPRISING A FIRST INDICATION OF THE FIRST MEASUREMENT AND A SECOND INDICATION OF THE SECOND MEASUREMENT
1620

FIG. 16

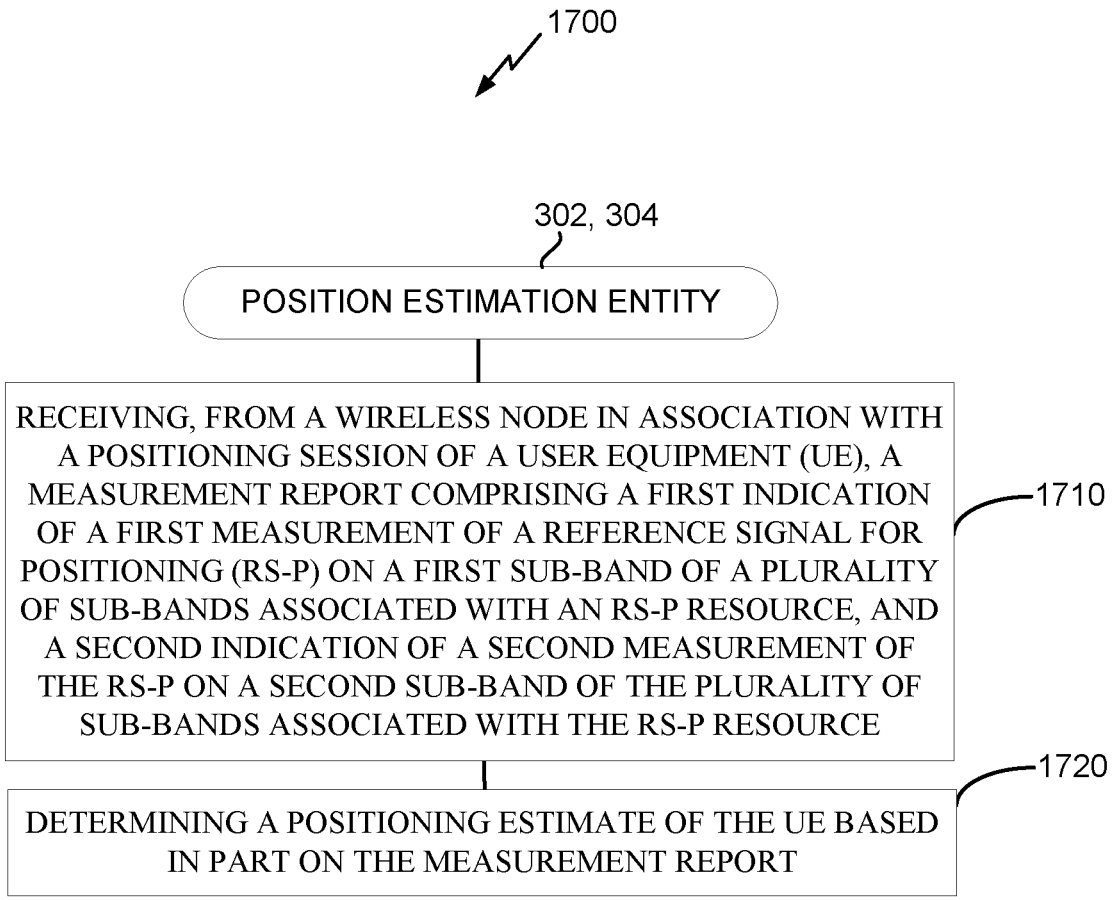

1700
302, 304
POSITION ESTIMATION ENTITY
RECEIVING, FROM A WIRELESS NODE IN ASSOCIATION WITH A POSITIONING SESSION OF A USER EQUIPMENT (UE), A MEASUREMENT REPORT COMPRISING A FIRST INDICATION OF A FIRST MEASUREMENT OF A REFERENCE SIGNAL FOR POSITIONING (RS-P) ON A FIRST SUB-BAND OF A PLURALITY OF SUB-BANDS ASSOCIATED WITH AN RS-P RESOURCE, AND A SECOND INDICATION OF A SECOND MEASUREMENT OF THE RS-P ON A SECOND SUB-BAND OF THE PLURALITY OF SUB-BANDS ASSOCIATED WITH THE RS-P RESOURCE
1710
DETERMINING A POSITIONING ESTIMATE OF THE UE BASED IN PART ON THE MEASUREMENT REPORT
1720

FIG. 17

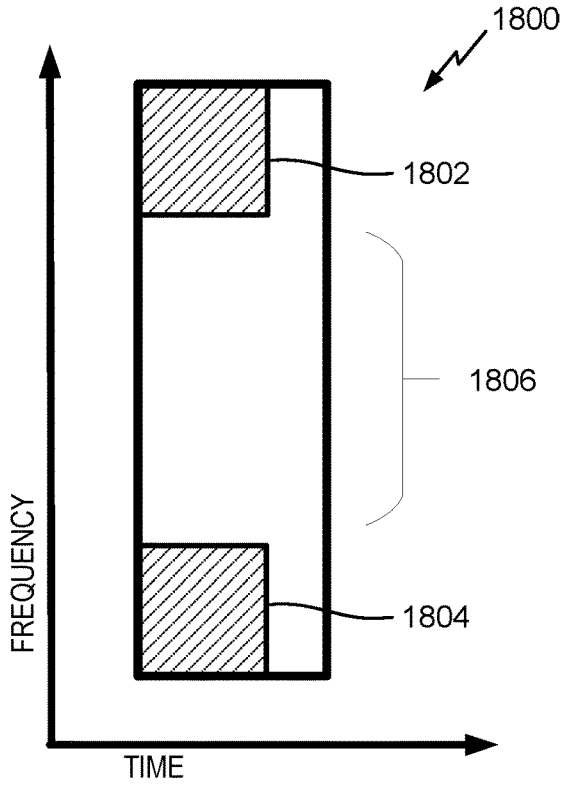

1800
1802
1806
1804
FREQUENCY
TIME

FIG. 18

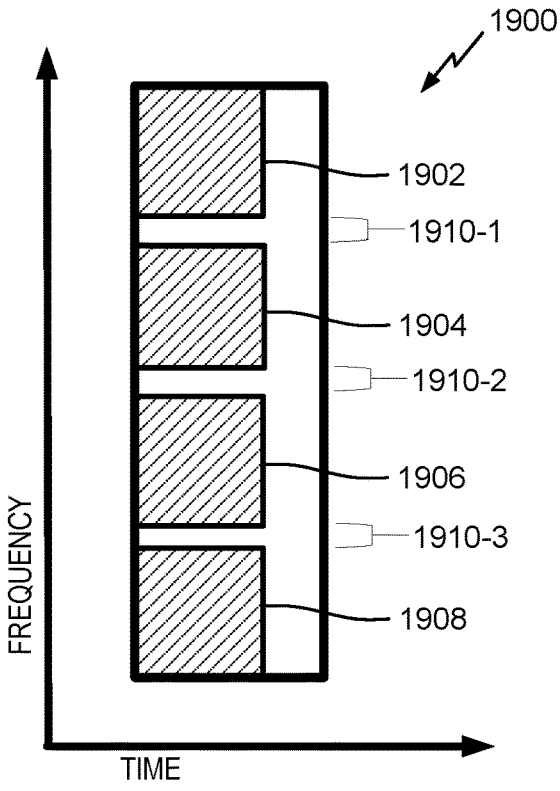

1900
1902
1910-1
1904
1910-2
1906
1910-3
1908
FREQUENCY
TIME

FIG. 19

MEASUREMENT REPORT WITH MEASUREMENT INDICATIONS FOR MULTIPLE SUB-BANDS OF A REFERENCE SIGNAL FOR POSITIONING RESOURCE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application for patent claims priority to Greek patent application Ser. No. 20210100146, entitled "MEASUREMENT REPORT WITH MEASUREMENT INDICATIONS FOR MULTIPLE SUB-BANDS OF A REFERENCE SIGNAL FOR POSITIONING RESOURCE," filed Mar. 10, 2021, and is a national stage application, filed under 35 U.S.C. § 371, of International Patent Application No. PCT/US2022/070513, entitled "MEASUREMENT REPORT WITH MEASUREMENT INDICATIONS FOR MULTIPLE SUB-BANDS OF A REFERENCE SIGNAL FOR POSITIONING RESOURCE," filed Feb. 3, 2022, both of which are assigned to the assignee hereof and expressly incorporated herein by reference in their entirety.

BACKGROUND OF THE DISCLOSURE

1. Field of the Disclosure

[0002] Aspects of the disclosure relate generally to wireless communications.

2. Description of the Related Art

[0003] Wireless communication systems have developed through various generations, including a first-generation analog wireless phone service (1G), a second-generation (2G) digital wireless phone service (including interim 2.5G and 2.75G networks), a third-generation (3G) high speed data, Internet-capable wireless service and a fourth-generation (4G) service (e.g., Long Term Evolution (LTE) or WiMax). There are presently many different types of wireless communication systems in use, including cellular and personal communications service (PCS) systems. Examples of known cellular systems include the cellular analog advanced mobile phone system (AMPS), and digital cellular systems based on code division multiple access (CDMA), frequency division multiple access (FDMA), time division multiple access (TDMA), the Global System for Mobile communications (GSM), etc.

[0004] A fifth generation (5G) wireless standard, referred to as New Radio (NR), calls for higher data transfer speeds, greater numbers of connections, and better coverage, among other improvements. The 5G standard, according to the Next Generation Mobile Networks Alliance, is designed to provide data rates of several tens of megabits per second to each of tens of thousands of users, with 1 gigabit per second to tens of workers on an office floor. Several hundreds of thousands of simultaneous connections should be supported in order to support large sensor deployments. Consequently, the spectral efficiency of 5G mobile communications should be significantly enhanced compared to the current 4G standard. Furthermore, signaling efficiencies should be enhanced and latency should be substantially reduced compared to current standards.

SUMMARY

[0005] The following presents a simplified summary relating to one or more aspects disclosed herein. Thus, the following summary should not be considered an extensive overview relating to all contemplated aspects, nor should the following summary be considered to identify key or critical elements relating to all contemplated aspects or to delineate the scope associated with any particular aspect. Accordingly, the following summary has the sole purpose to present certain concepts relating to one or more aspects relating to the mechanisms disclosed herein in a simplified form to precede the detailed description presented below.

[0006] In an aspect, a method of operating a wireless node includes performing a first measurement of a reference signal for positioning (RS-P) on a first sub-band of a plurality of sub-bands associated with an RS-P resource; performing a second measurement of the RS-P on a second sub-band of the plurality of sub-bands associated with the RS-P resource; and transmitting, to a position estimation entity in association with a positioning session of a user equipment (UE), a measurement report comprising a first indication of the first measurement and a second indication of the second measurement.

[0007] In an aspect, a method of operating a position estimation entity includes receiving, from a wireless node in association with a positioning session of a user equipment (UE), a measurement report comprising a first indication of a first measurement of a reference signal for positioning (RS-P) on a first sub-band of a plurality of sub-bands associated with an RS-P resource, and a second indication of a second measurement of the RS-P on a second sub-band of the plurality of sub-bands associated with the RS-P resource; and determining a positioning estimate of the UE based in part on the measurement report.

[0008] In an aspect, a wireless node includes a memory; at least one transceiver; and at least one processor communicatively coupled to the memory and the at least one transceiver, the at least one processor configured to: perform a first measurement of a reference signal for positioning (RS-P) on a first sub-band of a plurality of sub-bands associated with an RS-P resource; perform a second measurement of the RS-P on a second sub-band of the plurality of sub-bands associated with the RS-P resource; and transmit, to a position estimation entity in association with a positioning session of a user equipment (UE), a measurement report comprising a first indication of the first measurement and a second indication of the second measurement.

[0009] In an aspect, a position estimation entity includes a memory; at least one transceiver; and at least one processor communicatively coupled to the memory and the at least one transceiver, the at least one processor configured to: receive, from a wireless node in association with a positioning session of a user equipment (UE), a measurement report comprising a first indication of a first measurement of a reference signal for positioning (RS-P) on a first sub-band of a plurality of sub-bands associated with an RS-P resource, and a second indication of a second measurement of the RS-P on a second sub-band of the plurality of sub-bands associated with the RS-P resource; and determine a positioning estimate of the UE based in part on the measurement report.

[0010] Other objects and advantages associated with the aspects disclosed herein will be apparent to those skilled in the art based on the accompanying drawings and detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] The accompanying drawings are presented to aid in the description of various aspects of the disclosure and are provided solely for illustration of the aspects and not limitation thereof.

[0012] FIG. **1** illustrates an example wireless communications system, according to aspects of the disclosure.

[0013] FIGS. **2**A and **2**B illustrate example wireless network structures, according to aspects of the disclosure.

[0014] FIGS. **3**A to **3**C are simplified block diagrams of several sample aspects of components that may be employed in a user equipment (UE), a base station, and a network entity, respectively, and configured to support communications as taught herein.

[0015] FIG. **4** is a diagram illustrating an example base station in communication with an example UE, according to aspects of the disclosure.

[0016] FIG. **5** is a diagram illustrating the types of positioning error associated with a downlink or uplink angle-based positioning method, according to aspects of the disclosure.

[0017] FIG. **6** is a diagram illustrating aspects of downlink angle-of-departure (AoD) positioning, according to aspects of the disclosure.

[0018] FIG. **7** is a diagram illustrating a base station transmitting a first positioning reference signal (PRS) resource towards possible locations of a UE in the azimuth domain, according to aspects of the disclosure.

[0019] FIG. **8** is a graph illustrating an example beam response of the first PRS resource in FIG. **7** in the azimuth domain, according to aspects of the disclosure.

[0020] FIG. **9** is a diagram illustrating a base station transmitting a second PRS resource towards possible locations of a UE in the azimuth domain, according to aspects of the disclosure.

[0021] FIG. **10** is a graph illustrating an example beam response of the second PRS resource in FIG. **9** in the azimuth domain, according to aspects of the disclosure.

[0022] FIG. **11** is a graph illustrating an example beam response of three different PRS resources in the azimuth domain, according to aspects of the disclosure.

[0023] FIGS. **12**A to **12**D are diagrams illustrating example frame structures and channels within the frame structures, according to aspects of the disclosure.

[0024] FIG. **13** is a diagram of an example positioning reference signal (PRS) configuration for the PRS transmissions of a given base station, according to aspects of the disclosure.

[0025] FIG. **14** is a diagram of an example of frequency domain positioning reference signal (PRS) stitching, according to aspects of the disclosure.

[0026] FIG. **15** illustrates graphs depicting an example beam response of different PRS resources in the azimuth domain, according to aspects of the disclosure.

[0027] FIGS. **16** and **17** illustrate example methods of communication, according to aspects of the disclosure.

[0028] FIGS. **18** and **19** illustrates sub-band arrangements for PRS resources in accordance with aspects of the disclosure

DETAILED DESCRIPTION

[0029] Aspects of the disclosure are provided in the following description and related drawings directed to various examples provided for illustration purposes. Alternate aspects may be devised without departing from the scope of the disclosure. Additionally, well-known elements of the disclosure will not be described in detail or will be omitted so as not to obscure the relevant details of the disclosure.

[0030] The words "exemplary" and/or "example" are used herein to mean "serving as an example, instance, or illustration." Any aspect described herein as "exemplary" and/or "example" is not necessarily to be construed as preferred or advantageous over other aspects. Likewise, the term "aspects of the disclosure" does not require that all aspects of the disclosure include the discussed feature, advantage or mode of operation.

[0031] Those of skill in the art will appreciate that the information and signals described below may be represented using any of a variety of different technologies and techniques. For example, data, instructions, commands, information, signals, bits, symbols, and chips that may be referenced throughout the description below may be represented by voltages, currents, electromagnetic waves, magnetic fields or particles, optical fields or particles, or any combination thereof, depending in part on the particular application, in part on the desired design, in part on the corresponding technology, etc.

[0032] Further, many aspects are described in terms of sequences of actions to be performed by, for example, elements of a computing device. It will be recognized that various actions described herein can be performed by specific circuits (e.g., application specific integrated circuits (ASICs)), by program instructions being executed by one or more processors, or by a combination of both. Additionally, the sequence(s) of actions described herein can be considered to be embodied entirely within any form of non-transitory computer-readable storage medium having stored therein a corresponding set of computer instructions that, upon execution, would cause or instruct an associated processor of a device to perform the functionality described herein. Thus, the various aspects of the disclosure may be embodied in a number of different forms, all of which have been contemplated to be within the scope of the claimed subject matter. In addition, for each of the aspects described herein, the corresponding form of any such aspects may be described herein as, for example, "logic configured to" perform the described action.

[0033] As used herein, the terms "user equipment" (UE) and "base station" are not intended to be specific or otherwise limited to any particular radio access technology (RAT), unless otherwise noted. In general, a UE may be any wireless communication device (e.g., a mobile phone, router, tablet computer, laptop computer, consumer asset tracking device, wearable (e.g., smartwatch, glasses, augmented reality (AR)/virtual reality (VR) headset, etc.), vehicle (e.g., automobile, motorcycle, bicycle, etc.), Internet of Things (IoT) device, etc.) used by a user to communicate over a wireless communications network. A UE may be mobile or may (e.g., at certain times) be stationary, and may communicate with a radio access network (RAN). As used herein, the term "UE" may be referred to interchangeably as an "access terminal" or "AT," a "client device," a "wireless device," a "subscriber device," a "subscriber terminal," a "subscriber station," a "user terminal" or "UT," a "mobile device," a "mobile terminal," a "mobile station," or variations thereof. Generally, UEs can communicate with a core network via a RAN, and through the core network the UEs

can be connected with external networks such as the Internet and with other UEs. Of course, other mechanisms of connecting to the core network and/or the Internet are also possible for the UEs, such as over wired access networks, wireless local area network (WLAN) networks (e.g., based on the Institute of Electrical and Electronics Engineers (IEEE) 802.11 specification, etc.) and so on.

[0034] A base station may operate according to one of several RATs in communication with UEs depending on the network in which it is deployed, and may be alternatively referred to as an access point (AP), a network node, a NodeB, an evolved NodeB (eNB), a next generation eNB (ng-eNB), a New Radio (NR) Node B (also referred to as a gNB or gNodeB), etc. A base station may be used primarily to support wireless access by UEs, including supporting data, voice, and/or signaling connections for the supported UEs. In some systems a base station may provide purely edge node signaling functions while in other systems it may provide additional control and/or network management functions. A communication link through which UEs can send signals to a base station is called an uplink (UL) channel (e.g., a reverse traffic channel, a reverse control channel, an access channel, etc.). A communication link through which the base station can send signals to UEs is called a downlink (DL) or forward link channel (e.g., a paging channel, a control channel, a broadcast channel, a forward traffic channel, etc.). As used herein the term traffic channel (TCH) can refer to either an uplink/reverse or downlink/forward traffic channel.

[0035] The term "base station" may refer to a single physical transmission-reception point (TRP) or to multiple physical TRPs that may or may not be co-located. For example, where the term "base station" refers to a single physical TRP, the physical TRP may be an antenna of the base station corresponding to a cell (or several cell sectors) of the base station. Where the term "base station" refers to multiple co-located physical TRPs, the physical TRPs may be an array of antennas (e.g., as in a multiple-input multiple-output (MIMO) system or where the base station employs beamforming) of the base station. Where the term "base station" refers to multiple non-co-located physical TRPs, the physical TRPs may be a distributed antenna system (DAS) (a network of spatially separated antennas connected to a common source via a transport medium) or a remote radio head (RRH) (a remote base station connected to a serving base station). Alternatively, the non-co-located physical TRPs may be the serving base station receiving the measurement report from the UE and a neighbor base station whose reference radio frequency (RF) signals the UE is measuring. Because a TRP is the point from which a base station transmits and receives wireless signals, as used herein, references to transmission from or reception at a base station are to be understood as referring to a particular TRP of the base station.

[0036] In some implementations that support positioning of UEs, a base station may not support wireless access by UEs (e.g., may not support data, voice, and/or signaling connections for UEs), but may instead transmit reference signals to UEs to be measured by the UEs, and/or may receive and measure signals transmitted by the UEs. Such a base station may be referred to as a positioning beacon (e.g., when transmitting signals to UEs) and/or as a location measurement unit (e.g., when receiving and measuring signals from UEs).

[0037] An "RF signal" comprises an electromagnetic wave of a given frequency that transports information through the space between a transmitter and a receiver. As used herein, a transmitter may transmit a single "RF signal" or multiple "RF signals" to a receiver. However, the receiver may receive multiple "RF signals" corresponding to each transmitted RF signal due to the propagation characteristics of RF signals through multipath channels. The same transmitted RF signal on different paths between the transmitter and receiver may be referred to as a "multipath" RF signal.

[0038] FIG. **1** illustrates an example wireless communications system **100**. The wireless communications system **100** (which may also be referred to as a wireless wide area network (WWAN)) may include various base stations **102** and various UEs **104**. The base stations **102** may include macro cell base stations (high power cellular base stations) and/or small cell base stations (low power cellular base stations). In an aspect, the macro cell base station may include eNBs and/or ng-eNBs where the wireless communications system **100** corresponds to an LTE network, or gNBs where the wireless communications system **100** corresponds to a NR network, or a combination of both, and the small cell base stations may include femtocells, picocells, microcells, etc.

[0039] The base stations **102** may collectively form a RAN and interface with a core network **170** (e.g., an evolved packet core (EPC) or a 5G core (5GC)) through backhaul links **122**, and through the core network **170** to one or more location servers **172** (which may be part of core network **170** or may be external to core network **170**). In addition to other functions, the base stations **102** may perform functions that relate to one or more of transferring user data, radio channel ciphering and deciphering, integrity protection, header compression, mobility control functions (e.g., handover, dual connectivity), inter-cell interference coordination, connection setup and release, load balancing, distribution for non-access stratum (NAS) messages, NAS node selection, synchronization, RAN sharing, multimedia broadcast multicast service (MBMS), subscriber and equipment trace, RAN information management (RIM), paging, positioning, and delivery of warning messages. The base stations **102** may communicate with each other directly or indirectly (e.g., through the EPC/5GC) over backhaul links **134**, which may be wired or wireless.

[0040] The base stations **102** may wirelessly communicate with the UEs **104**. Each of the base stations **102** may provide communication coverage for a respective geographic coverage area **110**. In an aspect, one or more cells may be supported by a base station **102** in each geographic coverage area **110**. A "cell" is a logical communication entity used for communication with a base station (e.g., over some frequency resource, referred to as a carrier frequency, component carrier, carrier, band, or the like), and may be associated with an identifier (e.g., a physical cell identifier (PCI), a virtual cell identifier (VCI), a cell global identifier (CGI)) for distinguishing cells operating via the same or a different carrier frequency. In some cases, different cells may be configured according to different protocol types (e.g., machine-type communication (MTC), narrowband IoT (NB-IoT), enhanced mobile broadband (eMBB), or others) that may provide access for different types of UEs. Because a cell is supported by a specific base station, the term "cell" may refer to either or both of the logical communication entity and the base station that supports it, depending on the

context. In some cases, the term "cell" may also refer to a geographic coverage area of a base station (e.g., a sector), insofar as a carrier frequency can be detected and used for communication within some portion of geographic coverage areas **110**.

[0041] While neighboring macro cell base station **102** geographic coverage areas **110** may partially overlap (e.g., in a handover region), some of the geographic coverage areas **110** may be substantially overlapped by a larger geographic coverage area **110**. For example, a small cell (SC) base station **102'** may have a geographic coverage area **110'** that substantially overlaps with the geographic coverage area **110** of one or more macro cell base stations **102**. A network that includes both small cell and macro cell base stations may be known as a heterogeneous network. A heterogeneous network may also include home eNBs (HeNBs), which may provide service to a restricted group known as a closed subscriber group (CSG).

[0042] The communication links **120** between the base stations **102** and the UEs **104** may include uplink (also referred to as reverse link) transmissions from a UE **104** to a base station **102** and/or downlink (also referred to as forward link) transmissions from a base station **102** to a UE **104**. The communication links **120** may use MIMO antenna technology, including spatial multiplexing, beamforming, and/or transmit diversity. The communication links **120** may be through one or more carrier frequencies. Allocation of carriers may be asymmetric with respect to downlink and uplink (e.g., more or less carriers may be allocated for downlink than for uplink).

[0043] The wireless communications system **100** may further include a wireless local area network (WLAN) access point (AP) **150** in communication with WLAN stations (STAs) **152** via communication links **154** in an unlicensed frequency spectrum (e.g., 5 GHz). When communicating in an unlicensed frequency spectrum, the WLAN STAs **152** and/or the WLAN AP **150** may perform a clear channel assessment (CCA) or listen before talk (LBT) procedure prior to communicating in order to determine whether the channel is available.

[0044] The small cell base station **102'** may operate in a licensed and/or an unlicensed frequency spectrum. When operating in an unlicensed frequency spectrum, the small cell base station **102'** may employ LTE or NR technology and use the same 5 GHz unlicensed frequency spectrum as used by the WLAN AP **150**. The small cell base station **102'**, employing LTE/5G in an unlicensed frequency spectrum, may boost coverage to and/or increase capacity of the access network. NR in unlicensed spectrum may be referred to as NR-U. LTE in an unlicensed spectrum may be referred to as LTE-U, licensed assisted access (LAA), or MulteFire.

[0045] The wireless communications system **100** may further include a millimeter wave (mmW) base station **180** that may operate in mmW frequencies and/or near mmW frequencies in communication with a UE **182**. Extremely high frequency (EHF) is part of the RF in the electromagnetic spectrum. EHF has a range of 30 GHz to 300 GHz and a wavelength between 1 millimeter and 10 millimeters. Radio waves in this band may be referred to as a millimeter wave. Near mmW may extend down to a frequency of 3 GHz with a wavelength of 100 millimeters. The super high frequency (SHF) band extends between 3 GHz and 30 GHz, also referred to as centimeter wave. Communications using the mmW/near mmW radio frequency band have high path loss and a relatively short range. The mmW base station **180** and the UE **182** may utilize beamforming (transmit and/or receive) over a mmW communication link **184** to compensate for the extremely high path loss and short range. Further, it will be appreciated that in alternative configurations, one or more base stations **102** may also transmit using mmW or near mmW and beamforming. Accordingly, it will be appreciated that the foregoing illustrations are merely examples and should not be construed to limit the various aspects disclosed herein.

[0046] Transmit beamforming is a technique for focusing an RF signal in a specific direction. Traditionally, when a network node (e.g., a base station) broadcasts an RF signal, it broadcasts the signal in all directions (omni-directionally). With transmit beamforming, the network node determines where a given target device (e.g., a UE) is located (relative to the transmitting network node) and projects a stronger downlink RF signal in that specific direction, thereby providing a faster (in terms of data rate) and stronger RF signal for the receiving device(s). To change the directionality of the RF signal when transmitting, a network node can control the phase and relative amplitude of the RF signal at each of the one or more transmitters that are broadcasting the RF signal. For example, a network node may use an array of antennas (referred to as a "phased array" or an "antenna array") that creates a beam of RF waves that can be "steered" to point in different directions, without actually moving the antennas. Specifically, the RF current from the transmitter is fed to the individual antennas with the correct phase relationship so that the radio waves from the separate antennas add together to increase the radiation in a desired direction, while cancelling to suppress radiation in undesired directions.

[0047] Transmit beams may be quasi-co-located, meaning that they appear to the receiver (e.g., a UE) as having the same parameters, regardless of whether or not the transmitting antennas of the network node themselves are physically co-located. In NR, there are four types of quasi-co-location (QCL) relations. Specifically, a QCL relation of a given type means that certain parameters about a target reference RF signal on a target beam can be derived from information about a source reference RF signal on a source beam. If the source reference RF signal is QCL Type A, the receiver can use the source reference RF signal to estimate the Doppler shift, Doppler spread, average delay, and delay spread of a target reference RF signal transmitted on the same channel. If the source reference RF signal is QCL Type B, the receiver can use the source reference RF signal to estimate the Doppler shift and Doppler spread of a target reference RF signal transmitted on the same channel. If the source reference RF signal is QCL Type C, the receiver can use the source reference RF signal to estimate the Doppler shift and average delay of a target reference RF signal transmitted on the same channel. If the source reference RF signal is QCL Type D, the receiver can use the source reference RF signal to estimate the spatial receive parameter of a target reference RF signal transmitted on the same channel.

[0048] In receive beamforming, the receiver uses a receive beam to amplify RF signals detected on a given channel. For example, the receiver can increase the gain setting and/or adjust the phase setting of an array of antennas in a particular direction to amplify (e.g., to increase the gain level of) the RF signals received from that direction. Thus, when a receiver is said to beamform in a certain direction, it means

the beam gain in that direction is high relative to the beam gain along other directions, or the beam gain in that direction is the highest compared to the beam gain in that direction of all other receive beams available to the receiver. This results in a stronger received signal strength (e.g., reference signal received power (RSRP), reference signal received quality (RSRQ), signal-to-interference-plus-noise ratio (SINR), etc.) of the RF signals received from that direction.

[0049] Receive beams may be spatially related. A spatial relation means that parameters for a transmit beam for a second reference signal can be derived from information about a receive beam for a first reference signal. For example, a UE may use a particular receive beam to receive one or more reference downlink reference signals (e.g., positioning reference signals (PRS), tracking reference signals (TRS), phase tracking reference signal (PTRS), cell-specific reference signals (CRS), channel state information reference signals (CSI-RS), primary synchronization signals (PSS), secondary synchronization signals (SSS), synchronization signal blocks (SSBs), etc.) from a base station. The UE can then form a transmit beam for sending one or more uplink reference signals (e.g., uplink positioning reference signals (UL-PRS), sounding reference signal (SRS), demodulation reference signals (DMRS), PTRS, etc.) to that base station based on the parameters of the receive beam.

[0050] Note that a "downlink" beam may be either a transmit beam or a receive beam, depending on the entity forming it. For example, if a base station is forming the downlink beam to transmit a reference signal to a UE, the downlink beam is a transmit beam. If the UE is forming the downlink beam, however, it is a receive beam to receive the downlink reference signal. Similarly, an "uplink" beam may be either a transmit beam or a receive beam, depending on the entity forming it. For example, if a base station is forming the uplink beam, it is an uplink receive beam, and if a UE is forming the uplink beam, it is an uplink transmit beam.

[0051] In 5G, the frequency spectrum in which wireless nodes (e.g., base stations **102**/**180**, UEs **104**/**182**) operate is divided into multiple frequency ranges, FR1 (from 450 to 6000 MHz), FR2 (from 24250 to 52600 MHZ), FR3 (above 52600 MHZ), and FR4 (between FR1 and FR2). In a multi-carrier system, such as 5G, one of the carrier frequencies is referred to as the "primary carrier" or "anchor carrier" or "primary serving cell" or "PCell," and the remaining carrier frequencies are referred to as "secondary carriers" or "secondary serving cells" or "SCells." In carrier aggregation, the anchor carrier is the carrier operating on the primary frequency (e.g., FR1) utilized by a UE **104**/**182** and the cell in which the UE **104**/**182** either performs the initial radio resource control (RRC) connection establishment procedure or initiates the RRC connection re-establishment procedure. The primary carrier carries all common and UE-specific control channels, and may be a carrier in a licensed frequency (however, this is not always the case). A secondary carrier is a carrier operating on a second frequency (e.g., FR2) that may be configured once the RRC connection is established between the UE **104** and the anchor carrier and that may be used to provide additional radio resources. In some cases, the secondary carrier may be a carrier in an unlicensed frequency. The secondary carrier may contain only necessary signaling information and signals, for example, those that are UE-specific may not be present in the secondary carrier, since both primary uplink and downlink carriers are typically UE-specific. This means that different UEs **104**/**182** in a cell may have different downlink primary carriers. The same is true for the uplink primary carriers. The network is able to change the primary carrier of any UE **104**/**182** at any time. This is done, for example, to balance the load on different carriers. Because a "serving cell" (whether a PCell or an SCell) corresponds to a carrier frequency/component carrier over which some base station is communicating, the term "cell," "serving cell," "component carrier," "carrier frequency," and the like can be used interchangeably.

[0052] For example, still referring to FIG. **1**, one of the frequencies utilized by the macro cell base stations **102** may be an anchor carrier (or "PCell") and other frequencies utilized by the macro cell base stations **102** and/or the mmW base station **180** may be secondary carriers ("SCells"). The simultaneous transmission and/or reception of multiple carriers enables the UE **104**/**182** to significantly increase its data transmission and/or reception rates. For example, two 20 MHz aggregated carriers in a multi-carrier system would theoretically lead to a two-fold increase in data rate (i.e., 40 MHz), compared to that attained by a single 20 MHz carrier.

[0053] The wireless communications system **100** may further include a UE **164** that may communicate with a macro cell base station **102** over a communication link **120** and/or the mmW base station **180** over a mmW communication link **184**. For example, the macro cell base station **102** may support a PCell and one or more SCells for the UE **164** and the mmW base station **180** may support one or more SCells for the UE **164**.

[0054] In the example of FIG. **1**, one or more Earth orbiting satellite positioning system (SPS) space vehicles (SVs) **112** (e.g., satellites) may be used as an independent source of location information for any of the illustrated UEs (shown in FIG. **1** as a single UE **104** for simplicity). A UE **104** may include one or more dedicated SPS receivers specifically designed to receive SPS signals **124** for deriving geo location information from the SVs **112**. An SPS typically includes a system of transmitters (e.g., SVs **112**) positioned to enable receivers (e.g., UEs **104**) to determine their location on or above the Earth based, at least in part, on signals (e.g., SPS signals **124**) received from the transmitters. Such a transmitter typically transmits a signal marked with a repeating pseudo-random noise (PN) code of a set number of chips. While typically located in SVs **112**, transmitters may sometimes be located on ground-based control stations, base stations **102**, and/or other UEs **104**.

[0055] The use of SPS signals **124** can be augmented by various satellite-based augmentation systems (SBAS) that may be associated with or otherwise enabled for use with one or more global and/or regional navigation satellite systems. For example an SBAS may include an augmentation system(s) that provides integrity information, differential corrections, etc., such as the Wide Area Augmentation System (WAAS), the European Geostationary Navigation Overlay Service (EGNOS), the Multi-functional Satellite Augmentation System (MSAS), the Global Positioning System (GPS) Aided Geo Augmented Navigation or GPS and Geo Augmented Navigation system (GAGAN), and/or the like. Thus, as used herein, an SPS may include any combination of one or more global and/or regional navigation satellite systems and/or augmentation systems, and SPS signals **124** may include SPS, SPS-like, and/or other signals associated with such one or more SPS.

[0056] The wireless communications system **100** may further include one or more UEs, such as UE **190**, that connects indirectly to one or more communication networks via one or more device-to-device (D2D) peer-to-peer (P2P) links (referred to as "sidelinks"). In the example of FIG. **1**, UE **190** has a D2D P2P link **192** with one of the UEs **104** connected to one of the base stations **102** (e.g., through which UE **190** may indirectly obtain cellular connectivity) and a D2D P2P link **194** with WLAN STA **152** connected to the WLAN AP **150** (through which UE **190** may indirectly obtain WLAN-based Internet connectivity). In an example, the D2D P2P links **192** and **194** may be supported with any well-known D2D RAT, such as LTE Direct (LTE-D), WiFi Direct (WiFi-D), Bluetooth®, and so on.

[0057] FIG. **2**A illustrates an example wireless network structure **200**. For example, a 5GC **210** (also referred to as a Next Generation Core (NGC)) can be viewed functionally as control plane functions **214** (e.g., UE registration, authentication, network access, gateway selection, etc.) and user plane functions **212**, (e.g., UE gateway function, access to data networks, IP routing, etc.) which operate cooperatively to form the core network. User plane interface (NG-U) **213** and control plane interface (NG-C) **215** connect the gNB **222** to the 5GC **210** and specifically to the control plane functions **214** and user plane functions **212**. In an additional configuration, an ng-eNB **224** may also be connected to the 5GC **210** via NG-C **215** to the control plane functions **214** and NG-U **213** to user plane functions **212**. Further, ng-eNB **224** may directly communicate with gNB **222** via a backhaul connection **223**. In some configurations, the New RAN **220** may only have one or more gNBs **222**, while other configurations include one or more of both ng-eNBs **224** and gNBs **222**. Either gNB **222** or ng-eNB **224** may communicate with UEs **204** (e.g., any of the UEs depicted in FIG. **1**). Another optional aspect may include location server **230**, which may be in communication with the 5GC **210** to provide location assistance for UEs **204**. The location server **230** can be implemented as a plurality of separate servers (e.g., physically separate servers, different software modules on a single server, different software modules spread across multiple physical servers, etc.), or alternately may each correspond to a single server. The location server **230** can be configured to support one or more location services for UEs **204** that can connect to the location server **230** via the core network, 5GC **210**, and/or via the Internet (not illustrated). Further, the location server **230** may be integrated into a component of the core network, or alternatively may be external to the core network.

[0058] FIG. **2**B illustrates another example wireless network structure **250**. For example, a 5GC **260** can be viewed functionally as control plane functions, provided by an access and mobility management function (AMF) **264**, and user plane functions, provided by a user plane function (UPF) **262**, which operate cooperatively to form the core network (i.e., 5GC **260**). User plane interface **263** and control plane interface **265** connect the ng-eNB **224** to the 5GC **260** and specifically to UPF **262** and AMF **264**, respectively. In an additional configuration, a gNB **222** may also be connected to the 5GC **260** via control plane interface **265** to AMF **264** and user plane interface **263** to UPF **262**. Further, ng-eNB **224** may directly communicate with gNB **222** via the backhaul connection **223**, with or without gNB direct connectivity to the 5GC **260**. In some configurations, the New RAN **220** may only have one or more gNBs **222**, while other configurations include one or more of both ng-eNBs **224** and gNBs **222**. Either gNB **222** or ng-eNB **224** may communicate with UEs **204** (e.g., any of the UEs depicted in FIG. **1**). The base stations of the New RAN **220** communicate with the AMF **264** over the N2 interface and with the UPF **262** over the N3 interface.

[0059] The functions of the AMF **264** include registration management, connection management, reachability management, mobility management, lawful interception, transport for session management (SM) messages between the UE **204** and a session management function (SMF) **266**, transparent proxy services for routing SM messages, access authentication and access authorization, transport for short message service (SMS) messages between the UE **204** and the short message service function (SMSF) (not shown), and security anchor functionality (SEAF). The AMF **264** also interacts with an authentication server function (AUSF) (not shown) and the UE **204**, and receives the intermediate key that was established as a result of the UE **204** authentication process. In the case of authentication based on a UMTS (universal mobile telecommunications system) subscriber identity module (USIM), the AMF **264** retrieves the security material from the AUSF. The functions of the AMF **264** also include security context management (SCM). The SCM receives a key from the SEAF that it uses to derive access-network specific keys. The functionality of the AMF **264** also includes location services management for regulatory services, transport for location services messages between the UE **204** and a location management function (LMF) **270** (which acts as a location server **230**), transport for location services messages between the New RAN **220** and the LMF **270**, evolved packet system (EPS) bearer identifier allocation for interworking with the EPS, and UE **204** mobility event notification. In addition, the AMF **264** also supports functionalities for non-3GPP (Third Generation Partnership Project) access networks.

[0060] Functions of the UPF **262** include acting as an anchor point for intra-/inter-RAT mobility (when applicable), acting as an external protocol data unit (PDU) session point of interconnect to a data network (not shown), providing packet routing and forwarding, packet inspection, user plane policy rule enforcement (e.g., gating, redirection, traffic steering), lawful interception (user plane collection), traffic usage reporting, quality of service (QOS) handling for the user plane (e.g., uplink/downlink rate enforcement, reflective QoS marking in the downlink), uplink traffic verification (service data flow (SDF) to QoS flow mapping), transport level packet marking in the uplink and downlink, downlink packet buffering and downlink data notification triggering, and sending and forwarding of one or more "end markers" to the source RAN node. The UPF **262** may also support transfer of location services messages over a user plane between the UE **204** and a location server, such as a secure user plane location (SUPL) location platform (SLP) **272**.

[0061] The functions of the SMF **266** include session management, UE Internet protocol (IP) address allocation and management, selection and control of user plane functions, configuration of traffic steering at the UPF **262** to route traffic to the proper destination, control of part of policy enforcement and QoS, and downlink data notification. The interface over which the SMF **266** communicates with the AMF **264** is referred to as the N11 interface.

[0062] Another optional aspect may include an LMF **270**, which may be in communication with the 5GC **260** to provide location assistance for UEs **204**. The LMF **270** can be implemented as a plurality of separate servers (e.g., physically separate servers, different software modules on a single server, different software modules spread across multiple physical servers, etc.), or alternately may each correspond to a single server. The LMF **270** can be configured to support one or more location services for UEs **204** that can connect to the LMF **270** via the core network, 5GC **260**, and/or via the Internet (not illustrated). The SLP **272** may support similar functions to the LMF **270**, but whereas the LMF **270** may communicate with the AMF **264**, New RAN **220**, and UEs **204** over a control plane (e.g., using interfaces and protocols intended to convey signaling messages and not voice or data), the SLP **272** may communicate with UEs **204** and external clients (not shown in FIG. **2**B) over a user plane (e.g., using protocols intended to carry voice and/or data like the transmission control protocol (TCP) and/or IP).

[0063] FIGS. **3**A, **3**B, and **3**C illustrate several example components (represented by corresponding blocks) that may be incorporated into a UE **302** (which may correspond to any of the UEs described herein), a base station **304** (which may correspond to any of the base stations described herein), and a network entity **306** (which may correspond to or embody any of the network functions described herein, including the location server **230** and the LMF **270**) to support the file transmission operations as taught herein. It will be appreciated that these components may be implemented in different types of apparatuses in different implementations (e.g., in an ASIC, in a system-on-chip (SoC), etc.). The illustrated components may also be incorporated into other apparatuses in a communication system. For example, other apparatuses in a system may include components similar to those described to provide similar functionality. Also, a given apparatus may contain one or more of the components. For example, an apparatus may include multiple transceiver components that enable the apparatus to operate on multiple carriers and/or communicate via different technologies.

[0064] The UE **302** and the base station **304** each include wireless wide area network (WWAN) transceiver **310** and **350**, respectively, providing means for communicating (e.g., means for transmitting, means for receiving, means for measuring, means for tuning, means for refraining from transmitting, etc.) via one or more wireless communication networks (not shown), such as an NR network, an LTE network, a GSM network, and/or the like. The WWAN transceivers **310** and **350** may be connected to one or more antennas **316** and **356**, respectively, for communicating with other network nodes, such as other UEs, access points, base stations (e.g., eNBs, gNBs), etc., via at least one designated RAT (e.g., NR, LTE, GSM, etc.) over a wireless communication medium of interest (e.g., some set of time/frequency resources in a particular frequency spectrum). The WWAN transceivers **310** and **350** may be variously configured for transmitting and encoding signals **318** and **358** (e.g., messages, indications, information, and so on), respectively, and, conversely, for receiving and decoding signals **318** and **358** (e.g., messages, indications, information, pilots, and so on), respectively, in accordance with the designated RAT. Specifically, the WWAN transceivers **310** and **350** include one or more transmitters **314** and **354**, respectively, for transmitting and encoding signals **318** and **358**, respectively, and one or more receivers **312** and **352**, respectively, for receiving and decoding signals **318** and **358**, respectively.

[0065] The UE **302** and the base station **304** also include, at least in some cases, one or more short-range wireless transceivers **320** and **360**, respectively. The short-range wireless transceivers **320** and **360** may be connected to one or more antennas **326** and **366**, respectively, and provide means for communicating (e.g., means for transmitting, means for receiving, means for measuring, means for tuning, means for refraining from transmitting, etc.) with other network nodes, such as other UEs, access points, base stations, etc., via at least one designated RAT (e.g., WiFi, LTE-D, Bluetooth®, Zigbee®, Z-Wave®, PC5, dedicated short-range communications (DSRC), wireless access for vehicular environments (WAVE), near-field communication (NFC), etc.) over a wireless communication medium of interest. The short-range wireless transceivers **320** and **360** may be variously configured for transmitting and encoding signals **328** and **368** (e.g., messages, indications, information, and so on), respectively, and, conversely, for receiving and decoding signals **328** and **368** (e.g., messages, indications, information, pilots, and so on), respectively, in accordance with the designated RAT. Specifically, the short-range wireless transceivers **320** and **360** include one or more transmitters **324** and **364**, respectively, for transmitting and encoding signals **328** and **368**, respectively, and one or more receivers **322** and **362**, respectively, for receiving and decoding signals **328** and **368**, respectively. As specific examples, the short-range wireless transceivers **320** and **360** may be WiFi transceivers, Bluetooth® transceivers, Zigbee® and/or Z-Wave® transceivers, NFC transceivers, or vehicle-to-vehicle (V2V) and/or vehicle-to-everything (V2X) transceivers.

[0066] Transceiver circuitry including at least one transmitter and at least one receiver may comprise an integrated device (e.g., embodied as a transmitter circuit and a receiver circuit of a single communication device) in some implementations, may comprise a separate transmitter device and a separate receiver device in some implementations, or may be embodied in other ways in other implementations. In an aspect, a transmitter may include or be coupled to a plurality of antennas (e.g., antennas **316**, **326**, **356**, **366**), such as an antenna array, that permits the respective apparatus to perform transmit "beamforming," as described herein. Similarly, a receiver may include or be coupled to a plurality of antennas (e.g., antennas **316**, **326**, **356**, **366**), such as an antenna array, that permits the respective apparatus to perform receive beamforming, as described herein. In an aspect, the transmitter and receiver may share the same plurality of antennas (e.g., antennas **316**, **326**, **356**, **366**), such that the respective apparatus can only receive or transmit at a given time, not both at the same time. A wireless communication device (e.g., one or both of the transceivers **310** and **320** and/or **350** and **360**) of the UE **302** and/or the base station **304** may also comprise a network listen module (NLM) or the like for performing various measurements.

[0067] The UE **302** and the base station **304** also include, at least in some cases, satellite positioning systems (SPS) receivers **330** and **370**. The SPS receivers **330** and **370** may be connected to one or more antennas **336** and **376**, respectively, and may provide means for receiving and/or measuring SPS signals **338** and **378**, respectively, such as global positioning system (GPS) signals, global navigation satellite system (GLONASS) signals, Galileo signals, Beidou sig-

nals, Indian Regional Navigation Satellite System (NAVIC), Quasi-Zenith Satellite System (QZSS), etc. The SPS receivers **330** and **370** may comprise any suitable hardware and/or software for receiving and processing SPS signals **338** and **378**, respectively. The SPS receivers **330** and **370** request information and operations as appropriate from the other systems, and performs calculations necessary to determine positions of the UE **302** and the base station **304** using measurements obtained by any suitable SPS algorithm.

[0068] The base station **304** and the network entity **306** each include at least one network interfaces **380** and **390**, respectively, providing means for communicating (e.g., means for transmitting, means for receiving, etc.) with other network entities. For example, the network interfaces **380** and **390** (e.g., one or more network access ports) may be configured to communicate with one or more network entities via a wire-based or wireless backhaul connection. In some aspects, the network interfaces **380** and **390** may be implemented as transceivers configured to support wire-based or wireless signal communication. This communication may involve, for example, sending and receiving messages, parameters, and/or other types of information.

[0069] The UE **302**, the base station **304**, and the network entity **306** also include other components that may be used in conjunction with the operations as disclosed herein. The UE **302** includes processor circuitry implementing a processing system **332** for providing functionality relating to, for example, wireless positioning, and for providing other processing functionality. The base station **304** includes a processing system **384** for providing functionality relating to, for example, wireless positioning as disclosed herein, and for providing other processing functionality. The network entity **306** includes a processing system **394** for providing functionality relating to, for example, wireless positioning as disclosed herein, and for providing other processing functionality. The processing systems **332**, **384**, and **394** may therefore provide means for processing, such as means for determining, means for calculating, means for receiving, means for transmitting, means for indicating, etc. In an aspect, the processing systems **332**, **384**, and **394** may include, for example, one or more processors, such as one or more general purpose processors, multi-core processors, ASICs, digital signal processors (DSPs), field programmable gate arrays (FPGA), other programmable logic devices or processing circuitry, or various combinations thereof.

[0070] The UE **302**, the base station **304**, and the network entity **306** include memory circuitry implementing memory components **340**, **386**, and **396** (e.g., each including a memory device), respectively, for maintaining information (e.g., information indicative of reserved resources, thresholds, parameters, and so on). The memory components **340**, **386**, and **396** may therefore provide means for storing, means for retrieving, means for maintaining, etc. In some cases, the UE **302**, the base station **304**, and the network entity **306** may include positioning components **342**, **388**, and **398**, respectively. The positioning components **342**, **388**, and **398** may be hardware circuits that are part of or coupled to the processing systems **332**, **384**, and **394**, respectively, that, when executed, cause the UE **302**, the base station **304**, and the network entity **306** to perform the functionality described herein. In other aspects, the positioning components **342**, **388**, and **398** may be external to the processing systems **332**, **384**, and **394** (e.g., part of a modem processing system, integrated with another processing system, etc.). Alternatively, the positioning components **342**, **388**, and **398** may be memory modules stored in the memory components **340**, **386**, and **396**, respectively, that, when executed by the processing systems **332**, **384**, and **394** (or a modem processing system, another processing system, etc.), cause the UE **302**, the base station **304**, and the network entity **306** to perform the functionality described herein. FIG. **3**A illustrates possible locations of the positioning component **342**, which may be part of the WWAN transceiver **310**, the memory component **340**, the processing system **332**, or any combination thereof, or may be a standalone component. FIG. **3**B illustrates possible locations of the positioning component **388**, which may be part of the WWAN transceiver **350**, the memory component **386**, the processing system **384**, or any combination thereof, or may be a standalone component. FIG. **3**C illustrates possible locations of the positioning component **398**, which may be part of the network interface(s) **390**, the memory component **396**, the processing system **394**, or any combination thereof, or may be a standalone component.

[0071] The UE **302** may include one or more sensors **344** coupled to the processing system **332** to provide means for sensing or detecting movement and/or orientation information that is independent of motion data derived from signals received by the WWAN transceiver **310**, the short-range wireless transceiver **320**, and/or the SPS receiver **330**. By way of example, the sensor(s) **344** may include an accelerometer (e.g., a micro-electrical mechanical systems (MEMS) device), a gyroscope, a geomagnetic sensor (e.g., a compass), an altimeter (e.g., a barometric pressure altimeter), and/or any other type of movement detection sensor. Moreover, the sensor(s) **344** may include a plurality of different types of devices and combine their outputs in order to provide motion information. For example, the sensor(s) **344** may use a combination of a multi-axis accelerometer and orientation sensors to provide the ability to compute positions in 2D and/or 3D coordinate systems.

[0072] In addition, the UE **302** includes a user interface **346** providing means for providing indications (e.g., audible and/or visual indications) to a user and/or for receiving user input (e.g., upon user actuation of a sensing device such a keypad, a touch screen, a microphone, and so on). Although not shown, the base station **304** and the network entity **306** may also include user interfaces.

[0073] Referring to the processing system **384** in more detail, in the downlink, IP packets from the network entity **306** may be provided to the processing system **384**. The processing system **384** may implement functionality for an RRC layer, a packet data convergence protocol (PDCP) layer, a radio link control (RLC) layer, and a medium access control (MAC) layer. The processing system **384** may provide RRC layer functionality associated with broadcasting of system information (e.g., master information block (MIB), system information blocks (SIBs)), RRC connection control (e.g., RRC connection paging, RRC connection establishment, RRC connection modification, and RRC connection release), inter-RAT mobility, and measurement configuration for UE measurement reporting; PDCP layer functionality associated with header compression/decompression, security (ciphering, deciphering, integrity protection, integrity verification), and handover support functions; RLC layer functionality associated with the transfer of upper layer PDUs, error correction through automatic

repeat request (ARQ), concatenation, segmentation, and reassembly of RLC service data units (SDUs), re-segmentation of RLC data PDUs, and reordering of RLC data PDUs; and MAC layer functionality associated with mapping between logical channels and transport channels, scheduling information reporting, error correction, priority handling, and logical channel prioritization.

[0074] The transmitter **354** and the receiver **352** may implement Layer-1 (L1) functionality associated with various signal processing functions. Layer-1, which includes a physical (PHY) layer, may include error detection on the transport channels, forward error correction (FEC) coding/decoding of the transport channels, interleaving, rate matching, mapping onto physical channels, modulation/demodulation of physical channels, and MIMO antenna processing. The transmitter **354** handles mapping to signal constellations based on various modulation schemes (e.g., binary phase-shift keying (BPSK), quadrature phase-shift keying (QPSK), M-phase-shift keying (M-PSK), M-quadrature amplitude modulation (M-QAM)). The coded and modulated symbols may then be split into parallel streams. Each stream may then be mapped to an orthogonal frequency division multiplexing (OFDM) subcarrier, multiplexed with a reference signal (e.g., pilot) in the time and/or frequency domain, and then combined together using an inverse fast Fourier transform (IFFT) to produce a physical channel carrying a time domain OFDM symbol stream. The OFDM symbol stream is spatially precoded to produce multiple spatial streams. Channel estimates from a channel estimator may be used to determine the coding and modulation scheme, as well as for spatial processing. The channel estimate may be derived from a reference signal and/or channel condition feedback transmitted by the UE **302**. Each spatial stream may then be provided to one or more different antennas **356**. The transmitter **354** may modulate an RF carrier with a respective spatial stream for transmission.

[0075] At the UE **302**, the receiver **312** receives a signal through its respective antenna(s) **316**. The receiver **312** recovers information modulated onto an RF carrier and provides the information to the processing system **332**. The transmitter **314** and the receiver **312** implement Layer-1 functionality associated with various signal processing functions. The receiver **312** may perform spatial processing on the information to recover any spatial streams destined for the UE **302**. If multiple spatial streams are destined for the UE **302**, they may be combined by the receiver **312** into a single OFDM symbol stream. The receiver **312** then converts the OFDM symbol stream from the time-domain to the frequency domain using a fast Fourier transform (FFT). The frequency domain signal comprises a separate OFDM symbol stream for each subcarrier of the OFDM signal. The symbols on each subcarrier, and the reference signal, are recovered and demodulated by determining the most likely signal constellation points transmitted by the base station **304**. These soft decisions may be based on channel estimates computed by a channel estimator. The soft decisions are then decoded and de-interleaved to recover the data and control signals that were originally transmitted by the base station **304** on the physical channel. The data and control signals are then provided to the processing system **332**, which implements Layer-3 (L3) and Layer-2 (L2) functionality.

[0076] In the uplink, the processing system **332** provides demultiplexing between transport and logical channels, packet reassembly, deciphering, header decompression, and control signal processing to recover IP packets from the core network. The processing system **332** is also responsible for error detection.

[0077] Similar to the functionality described in connection with the downlink transmission by the base station **304**, the processing system **332** provides RRC layer functionality associated with system information (e.g., MIB, SIBs) acquisition, RRC connections, and measurement reporting; PDCP layer functionality associated with header compression/decompression, and security (ciphering, deciphering, integrity protection, integrity verification); RLC layer functionality associated with the transfer of upper layer PDUs, error correction through ARQ, concatenation, segmentation, and reassembly of RLC SDUs, re-segmentation of RLC data PDUs, and reordering of RLC data PDUs; and MAC layer functionality associated with mapping between logical channels and transport channels, multiplexing of MAC SDUs onto transport blocks (TBs), demultiplexing of MAC SDUs from TBs, scheduling information reporting, error correction through hybrid automatic repeat request (HARQ), priority handling, and logical channel prioritization.

[0078] Channel estimates derived by the channel estimator from a reference signal or feedback transmitted by the base station **304** may be used by the transmitter **314** to select the appropriate coding and modulation schemes, and to facilitate spatial processing. The spatial streams generated by the transmitter **314** may be provided to different antenna(s) **316**. The transmitter **314** may modulate an RF carrier with a respective spatial stream for transmission.

[0079] The uplink transmission is processed at the base station **304** in a manner similar to that described in connection with the receiver function at the UE **302**. The receiver **352** receives a signal through its respective antenna(s) **356**. The receiver **352** recovers information modulated onto an RF carrier and provides the information to the processing system **384**.

[0080] In the uplink, the processing system **384** provides demultiplexing between transport and logical channels, packet reassembly, deciphering, header decompression, control signal processing to recover IP packets from the UE **302**. IP packets from the processing system **384** may be provided to the core network. The processing system **384** is also responsible for error detection.

[0081] For convenience, the UE **302**, the base station **304**, and/or the network entity **306** are shown in FIGS. **3**A-C as including various components that may be configured according to the various examples described herein. It will be appreciated, however, that the illustrated blocks may have different functionality in different designs.

[0082] The various components of the UE **302**, the base station **304**, and the network entity **306** may communicate with each other over data buses **334**, **382**, and **392**, respectively. The components of FIGS. **3**A-C may be implemented in various ways. In some implementations, the components of FIGS. **3**A-C may be implemented in one or more circuits such as, for example, one or more processors and/or one or more ASICs (which may include one or more processors). Here, each circuit may use and/or incorporate at least one memory component for storing information or executable code used by the circuit to provide this functionality. For example, some or all of the functionality represented by blocks **310** to **346** may be implemented by processor and memory component(s) of the UE **302** (e.g., by execution of appropriate code and/or by appropriate configuration of

processor components). Similarly, some or all of the functionality represented by blocks **350** to **388** may be implemented by processor and memory component(s) of the base station **304** (e.g., by execution of appropriate code and/or by appropriate configuration of processor components). Also, some or all of the functionality represented by blocks **390** to **398** may be implemented by processor and memory component(s) of the network entity **306** (e.g., by execution of appropriate code and/or by appropriate configuration of processor components). For simplicity, various operations, acts, and/or functions are described herein as being performed "by a UE," "by a base station," "by a network entity," etc. However, as will be appreciated, such operations, acts, and/or functions may actually be performed by specific components or combinations of components of the UE **302**, base station **304**, network entity **306**, etc., such as the processing systems **332**, **384**, **394**, the transceivers **310**, **320**, **350**, and **360**, the memory components **340**, **386**, and **396**, the positioning components **342**, **388**, and **398**, etc.

[0083] NR supports a number of cellular network-based positioning technologies, including downlink-based, uplink-based, and downlink-and-uplink-based positioning methods. Downlink-based positioning methods include observed time difference of arrival (OTDOA) in LTE, downlink time difference of arrival (DL-TDOA) in NR, and downlink angle-of-departure (DL-AoD) in NR. In an OTDOA or DL-TDOA positioning procedure, a UE measures the differences between the times of arrival (ToAs) of reference signals (e.g., PRS, TRS, CSI-RS, SSB, etc.) received from pairs of base stations, referred to as reference signal time difference (RSTD) or time difference of arrival (TDOA) measurements, and reports them to a positioning entity. More specifically, the UE receives the identifiers (IDs) of a reference base station (e.g., a serving base station) and multiple non-reference base stations in assistance data. The UE then measures the RSTD between the reference base station and each of the non-reference base stations. Based on the known locations of the involved base stations and the RSTD measurements, the positioning entity can estimate the UE's location. For DL-AoD positioning, a base station measures the angle and other channel properties (e.g., signal strength) of the downlink transmit beam used to communicate with a UE to estimate the location of the UE.

[0084] Uplink-based positioning methods include uplink time difference of arrival (UL-TDOA) and uplink angle-of-arrival (UL-AoA). UL-TDOA is similar to DL-TDOA, but is based on uplink reference signals (e.g., SRS) transmitted by the UE. For UL-AoA positioning, a base station measures the angle and other channel properties (e.g., gain level) of the uplink receive beam used to communicate with a UE to estimate the location of the UE.

[0085] Downlink-and-uplink-based positioning methods include enhanced cell-ID (E-CID) positioning and multi-round-trip-time (RTT) positioning (also referred to as "multi-cell RTT"). In an RTT procedure, an initiator (a base station or a UE) transmits an RTT measurement signal (e.g., a PRS or SRS) to a responder (a UE or base station), which transmits an RTT response signal (e.g., an SRS or PRS) back to the initiator. The RTT response signal includes the difference between the ToA of the RTT measurement signal and the transmission time of the RTT response signal, referred to as the reception-to-transmission (Rx-Tx) measurement. The initiator calculates the difference between the transmission time of the RTT measurement signal and the ToA of the RTT response signal, referred to as the "Tx-Rx" measurement. The propagation time (also referred to as the "time of flight") between the initiator and the responder can be calculated from the Tx-Rx and Rx-Tx measurements. Based on the propagation time and the known speed of light, the distance between the initiator and the responder can be determined. For multi-RTT positioning, a UE performs an RTT procedure with multiple base stations to enable its location to be triangulated based on the known locations of the base stations. RTT and multi-RTT methods can be combined with other positioning techniques, such as UL-AoA and DL-AoD, to improve location accuracy.

[0086] The E-CID positioning method is based on radio resource management (RRM) measurements. In E-CID, the UE reports the serving cell ID, the timing advance (TA), and the identifiers, estimated timing, and signal strength of detected neighbor base stations. The location of the UE is then estimated based on this information and the known locations of the base stations.

[0087] To assist positioning operations, a location server (e.g., location server **230**, LMF **270**, SLP **272**) may provide assistance data to the UE. For example, the assistance data may include identifiers of the base stations (or the cells/TRPs of the base stations) from which to measure reference signals, the reference signal configuration parameters (e.g., the number of consecutive positioning subframes, periodicity of positioning subframes, muting sequence, frequency hopping sequence, reference signal identifier, reference signal bandwidth, etc.), and/or other parameters applicable to the particular positioning method. Alternatively, the assistance data may originate directly from the base stations themselves (e.g., in periodically broadcasted overhead messages, etc.). in some cases, the UE may be able to detect neighbor network nodes itself without the use of assistance data.

[0088] In the case of an OTDOA or DL-TDOA positioning procedure, the assistance data may further include an expected RSTD value and an associated uncertainty, or search window, around the expected RSTD. In some cases, the value range of the expected RSTD may be +/−500 microseconds (μs). In some cases, when any of the resources used for the positioning measurement are in FR1, the value range for the uncertainty of the expected RSTD may be +/−32 μs. In other cases, when all of the resources used for the positioning measurement(s) are in FR2, the value range for the uncertainty of the expected RSTD may be +/−8 μs.

[0089] A location estimate may be referred to by other names, such as a position estimate, location, position, position fix, fix, or the like. A location estimate may be geodetic and comprise coordinates (e.g., latitude, longitude, and possibly altitude) or may be civic and comprise a street address, postal address, or some other verbal description of a location. A location estimate may further be defined relative to some other known location or defined in absolute terms (e.g., using latitude, longitude, and possibly altitude). A location estimate may include an expected error or uncertainty (e.g., by including an area or volume within which the location is expected to be included with some specified or default level of confidence).

[0090] FIG. **4** is a diagram **400** illustrating a base station (BS) **402** (which may correspond to any of the base stations described herein) in communication with a UE **404** (which may correspond to any of the UEs described herein). Referring to FIG. **4**, the base station **402** may transmit a beam-

formed signal to the UE **404** on one or more transmit beams **402***a*, **402***b*, **402***c*, **402***d*, **402***e*, **402***f*, **402***g*, **402***h*, each having a beam identifier that can be used by the UE **404** to identify the respective beam. Where the base station **402** is beamforming towards the UE **404** with a single array of antennas (e.g., a single TRP/cell), the base station **402** may perform a "beam sweep" by transmitting first beam **402***a*, then beam **402***b*, and so on until lastly transmitting beam **402***h*. Alternatively, the base station **402** may transmit beams **402***a*-**402***h* in some pattern, such as beam **402***a*, then beam **402***h*, then beam **402***b*, then beam **402***g*, and so on. Where the base station **402** is beamforming towards the UE **404** using multiple arrays of antennas (e.g., multiple TRPs/cells), each antenna array may perform a beam sweep of a subset of the beams **402***a*-**402***h*. Alternatively, each of beams **402***a*-**402***h* may correspond to a single antenna or antenna array.

[0091] FIG. **4** further illustrates the paths **412***c*, **412***d*, **412***e*, **412***f*, and **412***g* followed by the beamformed signal transmitted on beams **402***c*, **402***d*, **402***e*, **402***f*, and **402***g*, respectively. Each path **412***c*, **412***d*, **412***e*, **412***f*, **412***g* may correspond to a single "multipath" or, due to the propagation characteristics of radio frequency (RF) signals through the environment, may be comprised of a plurality (a cluster) of "multipaths." Note that although only the paths for beams **402***c*-**402***g* are shown, this is for simplicity, and the signal transmitted on each of beams **402***a*-**402***h* will follow some path. In the example shown, the paths **412***c*, **412***d*, **412***e*, and **412***f* are straight lines, while path **412***g* reflects off an obstacle **420** (e.g., a building, vehicle, terrain feature, etc.).

[0092] The UE **404** may receive the beamformed signal from the base station **402** on one or more receive beams **404***a*, **404***b*, **404***c*, **404***d*. Note that for simplicity, the beams illustrated in FIG. **4** represent either transmit beams or receive beams, depending on which of the base station **402** and the UE **404** is transmitting and which is receiving. Thus, the UE **404** may also transmit a beamformed signal to the base station **402** on one or more of the beams **404***a*-**404***d*, and the base station **402** may receive the beamformed signal from the UE **404** on one or more of the beams **402***a*-**402***h*.

[0093] In an aspect, the base station **402** and the UE **404** may perform beam training to align the transmit and receive beams of the base station **402** and the UE **404**. For example, depending on environmental conditions and other factors, the base station **402** and the UE **404** may determine that the best transmit and receive beams are **402***d* and **404***b*, respectively, or beams **402***e* and **404***c*, respectively. The direction of the best transmit beam for the base station **402** may or may not be the same as the direction of the best receive beam, and likewise, the direction of the best receive beam for the UE **404** may or may not be the same as the direction of the best transmit beam. Note, however, that aligning the transmit and receive beams is not necessary to perform a downlink angle-of-departure (DL-AoD) or uplink angle-of-arrival (UL-AoA) positioning procedure.

[0094] To perform a DL-AoD positioning procedure, the base station **402** may transmit reference signals (e.g., PRS, CRS, TRS, CSI-RS, PSS, SSS, etc.) to the UE **404** on one or more of beams **402***a*-**402***h*, with each beam having a different transmit angle. The different transmit angles of the beams will result in different received signal strengths (e.g., RSRP, RSRQ, SINR, etc.) at the UE **404**. Specifically, the received signal strength will be lower for transmit beams **402***a*-**402***h* that are further from the line of sight (LOS) path **410** between the base station **402** and the UE **404** than for transmit beams **402***a*-**402***h* that are closer to the LOS path **410**.

[0095] In the example of FIG. **4**, if the base station **402** transmits reference signals to the UE **404** on beams **402***c*, **402***d*, **402***e*, **402***f*, and **402***g*, then transmit beam **402***e* is best aligned with the LOS path **410**, while transmit beams **402***c*, **402***d*, **402***f*, and **402***g* are not. As such, beam **402***e* is likely to have a higher received signal strength at the UE **404** than beams **402***c*, **402***d*, **402***f*, and **402***g*. Note that the reference signals transmitted on some beams (e.g., beams **402***c* and/or **402***f*) may not reach the UE **404**, or energy reaching the UE **404** from these beams may be so low that the energy may not be detectable or at least can be ignored.

[0096] The UE **404** can report the received signal strength, and optionally, the associated measurement quality, of each measured transmit beam **402***c*-**402***g* to the base station **402**, or alternatively, the identity of the transmit beam having the highest received signal strength (beam **402***e* in the example of FIG. **4**). Alternatively or additionally, if the UE **404** is also engaged in a round-trip-time (RTT) or time-difference of arrival (TDOA) positioning session with at least one base station **402** or a plurality of base stations **402**, respectively, the UE **404** can report reception-to-transmission (Rx-Tx) or reference signal time difference (RSTD) measurements (and optionally the associated measurement qualities), respectively, to the serving base station **402** or other positioning entity. In any case, the positioning entity (e.g., the base station **402**, a location server, a third-party client, UE **404**, etc.) can estimate the angle from the base station **402** to the UE **404** as the AoD of the transmit beam having the highest received signal strength at the UE **404**, here, transmit beam **402***e*.

[0097] In one aspect of DL-AoD-based positioning, where there is only one involved base station **402**, the base station **402** and the UE **404** can perform a round-trip-time (RTT) procedure to determine the distance between the base station **402** and the UE **404**. Thus, the positioning entity can determine both the direction to the UE **404** (using DL-AoD positioning) and the distance to the UE **404** (using RTT positioning) to estimate the location of the UE **404**. Note that the AoD of the transmit beam having the highest received signal strength does not necessarily lie along the LOS path **410**, as shown in FIG. **4**. However, for DL-AoD-based positioning purposes, it is assumed to do so.

[0098] In another aspect of DL-AoD-based positioning, where there are multiple involved base stations **402**, each base station **402** can report the determined AoD to the UE **404** to the positioning entity. The positioning entity receives multiple such AoDs from a plurality of involved base stations **402** (or other geographically separated transmission points) for the UE **404**. With this information, and knowledge of the base stations' **402** geographic locations, the positioning entity can estimate a location of the UE **404** as the intersection of the received AoDs. There should be at least two involved base stations **402** for a two-dimensional (2D) location solution, but as will be appreciated, the more base stations **402** that are involved in the positioning procedure, the more accurate the estimated location of the UE **404** will be.

[0099] To perform an UL-AoA positioning procedure, the UE **404** transmits uplink reference signals (e.g., UL-PRS, SRS, DMRS, etc.) to the base station **402** on one or more of uplink transmit beams **404***a*-**404***d*. The base station **402**

receives the uplink reference signals on one or more of uplink receive beams **402***a*-**402***h*. The base station **402** determines the angle of the best receive beams **402***a*-**402***h* used to receive the one or more reference signals from the UE **404** as the AoA from itself to the UE **404**. Specifically, each of the receive beams **402***a*-**402***h* will result in a different received signal strength (e.g., RSRP, RSRQ, SINR, etc.) of the one or more reference signals at the base station **402**. Further, the channel impulse response of the one or more reference signals will be smaller for receive beams **402***a*-**402***h* that are further from the actual LOS path between the base station **402** and the UE **404** than for receive beams **402***a*-**402***h* that are closer to the LOS path. Likewise, the received signal strength will be lower for receive beams **402***a*-**402***h* that are further from the LOS path than for receive beams **402***a*-**402***h* that are closer to the LOS path. As such, the base station **402** identifies the receive beam **402***a*-**402***h* that results in the highest received signal strength and, optionally, the strongest channel impulse response, and estimates the angle from itself to the UE **404** as the AoA of that receive beam **402***a*-**402***h*. Note that as with DL-AoD-based positioning, the AoA of the receive beam **402***a*-**402***h* resulting in the highest received signal strength (and strongest channel impulse response if measured) does not necessarily lie along the LOS path **410**. However, for UL-AoA-based positioning purposes, it is assumed to do so.

[0100] Note that while the UE **404** is illustrated as being capable of beamforming, this is not necessary for DL-AoD and UL-AoA positioning procedures. Rather, the UE **404** may receive and transmit on an omni-directional antenna.

[0101] Where the UE **404** is estimating its location (i.e., the UE is the positioning entity), it needs to obtain the geographic location of the base station **402**. The UE **404** may obtain the location from, for example, the base station **402** itself or a location server (e.g., location server **230**, LMF **270**, SLP **272**). With the knowledge of the distance to the base station **402** (based on the RTT or timing advance), the angle between the base station **402** and the UE **404** (based on the UL-AoA of the best receive beam **402***a*-**402***h*), and the known geographic location of the base station **402**, the UE **404** can estimate its location.

[0102] Alternatively, where a positioning entity, such as the base station **402** or a location server, is estimating the location of the UE **404**, the base station **402** reports the AoA of the receive beam **402***a*-**402***h* resulting in the highest received signal strength (and optionally strongest channel impulse response) of the reference signals received from the UE **404**, or all received signal strengths and channel impulse responses for all receive beams **402** (which allows the positioning entity to determine the best receive beam **402***a*-**402***h*). The base station **402** may additionally report the distance to the UE **404**. The positioning entity can then estimate the location of the UE **404** based on the UE's **404** distance to the base station **402**, the AoA of the identified receive beam **402***a*-**402***h*, and the known geographic location of the base station **402**.

[0103] There are various motivations for enhancing angle-based positioning methods (e.g., DL-AoD, UL-AoA). For example, the bandwidth of the measured signals does not significantly affect the precision of angle-based methods. As another example, angle-based methods are not sensitive to network synchronization errors. As yet another example, massive MIMO is available in both FR1 and FR2, thereby enabling angle measurement. As another example, DL-AoD is supported for UE-based positioning, and UL-AoA can supplement RTT or uplink-based positioning methods naturally without additional overhead.

[0104] FIG. **5** is a diagram illustrating the types of positioning errors associated with a downlink or uplink angle-based positioning method (e.g., DL-AoD, UL-AoA), according to aspects of the disclosure. In the example of FIG. **5**, a base station **502** (e.g., any of the base stations described herein) is beamforming towards a UE **504** (e.g., any of the UEs described herein). The base station **502** may transmit downlink reference signals (e.g., PRS) to the UE **504** and/or receive uplink reference signals (e.g., SRS) from the UE **504** on multiple beams **510**. In the former case, the beams **510** may be downlink transmit beams, and in the latter case, the beams **510** may be uplink receive beams.

[0105] As shown in FIG. **5**, the location of the UE **504** is on a circumference defined by the radius of the cell (i.e., the distance between base station **502** and the UE **504**) and the angle and width of the best beam **510** used to communicate with the UE **504**. The UE's **504** location can therefore be estimated based on the location of the base station **502**, the cell radius, and the angle and width of the best beam **510**. The UE's **504** estimated location is subject to different types of errors, however. Specifically, there is an angle estimation error (i.e., an error in the estimated angle of the best beam **510**) and a position error along the circumference (i.e., an error in the UE's **504** location on the circumference defined by the angle and width of the best beam **510**).

[0106] The following table illustrates example position errors (along the circumference) based on different angle estimation errors. Specifically, the rows show the position error given a specific angle error (leftmost column) and cell radius. The last row shows the implied standard deviation (ISD) for each example cell radius.

TABLE 1

Angle Error	Cell radius (meters)						
(degrees)	10	50	100	116	200	289	500
1	0.2	0.9	1.7	2.0	3.5	5.0	8.7
2	0.3	1.7	3.5	4.0	7.0	10.1	17.5
5	0.9	4.4	8.7	10.1	17.5	25.2	43.7
10	1.7	8.7	17.5	20.2	35.0	50.5	87.5
ISD (meters)	17	87	173	200	346	500	866

[0107] As shown in Table 1 above, the angle accuracy (or angle error) should be within a few degrees to provide a noticeable impact to the positioning accuracy. For example, as shown in Table 1, at 200 meters ISD, the angle error should be within one to two degrees to keep the position error lower than three meters.

[0108] FIG. **6** is a diagram **600** illustrating further aspects of DL-AoD positioning, according to aspects of the disclosure. In the example of FIG. **6**, a TRP **602** (e.g., a TRP of any of the base stations described herein) is beamforming towards a UE **604** (e.g., any of the UEs described herein). The TRP **602** may transmit downlink reference signals (e.g., PRS) to the UE **604** on multiple downlink transmit beams, labeled "1," "2," "3," "4," and "5."

[0109] Each potential location of the UE **604** around the TRP **602** in the azimuth domain may be represented as ϕ_k. For simplicity, FIG. **6** illustrates only four possible locations of the UE **604** around the TRP **602**, denoted ϕ_1, ϕ_2, ϕ_3, and ϕ_N. For a DL-AoD positioning session, the UE **604** measures

the signal strength (e.g., RSRP) of each detectable downlink transmit beam from the TRP **602**. The circled points on each line between the TRP **602** and an illustrated location of the UE **604** indicate where on the measurable beams the signal strength measurements will be taken. That is, the circles represent the relative signal strength that the UE **604** will measure for each beam intersecting the line, with circles closer to the UE **604** indicating a higher signal strength.

[0110] For each potential $\phi_k \in [\phi_1, \ldots, \phi_N]$ at which the UE **604** may be located, and for each beam $l \in [1, \ldots, N_{beams}]$ that is being transmitted, the TRP **602** calculates the expected signal strength/receive power $P_{i,k}$ at the UE **604**. The TRP **602** derives the normalized vector P_k, for each $k \in [1, \ldots N]$, as:

$$P_k = \begin{bmatrix} \frac{P_{i,1}}{\max_l (P_{i,l})} \\ \vdots \\ \frac{P_{i,N_{beams}}}{\max_l (P_{i,l})} \end{bmatrix}$$

[0111] The TRP **602** then transmits the PRS resources to the UE **604** on the downlink transmit beams. Each beam may correspond to a different PRS resource, or the same PRS resource may be transmitted on each beam, or some combination thereof. The UE **604** can report up to eight RSRPs, with one for each PRS resource. The TRP **602** (or other positioning entity) denotes as $\hat{P}$ the received vector of normalized RSRP, and finds the $\hat{k}$ that results in a $P_{\hat{k}}$ close to $\hat{P}$.

[0112] To derive the vectors $\{P_k\}_{k=1}^{N}$, the involved base stations need to report the vectors to the location server or the UE (i.e., the positioning entity), or report the beam response for each PRS resource. FIG. **7** is a diagram **700** illustrating a TRP **702** (e.g., a TRP of any of the base stations described herein) transmitting a first PRS resource (labeled "PRS1") towards possible locations of a UE **704** (e.g., any of the UEs described herein) in the azimuth domain. FIG. **8** is a graph **800** illustrating the beam response of PRS1 from FIG. **7** in the azimuth domain. The beam response is the shape of the beam as transmitted by the base station (here, TRP **702**). The horizontal axis of graph **800** represents the azimuth angle (in degrees) and the vertical axis represents the beam response (normalized to '1').

[0113] FIG. **9** is a diagram **900** illustrating a TRP **902** (e.g., a TRP of any of the base stations described herein) transmitting a second PRS resource (labeled "PRS2") towards possible locations of a UE **904** (e.g., any of the UEs described herein) in the azimuth domain. FIG. **10** is a graph **1000** illustrating the beam response of PRS2 from FIG. **9** in the azimuth domain. The horizontal axis of graph **1000** represents the azimuth angle (in degrees) and the vertical axis represents the beam response (normalized to '1').

[0114] FIG. **11** is a graph **1100** illustrating the beam responses of three different PRS resources in the azimuth domain. That is, graph **1100** illustrates the beam shape for three downlink beams on which a base station transmits DL-PRS. The horizontal axis of graph **1100** represents the azimuth angle (in degrees) and the vertical axis represents the beam response (normalized to '1'). For each azimuth angle, the relative beam response is the information that is being used to compare against the reported relative RSRP. For example, a UE located at −20 degrees in the azimuth domain would be expected to report RSRP values for the three downlink transmit beams that correspond to the points on the illustrated beam responses that intersect the vertical line at −20 degrees. Note that the UE may not report the exact expected RSRP values, but the series of RSRP values that it does report should be able to be matched to a location in the azimuth domain based on the beam responses, here, −20 degrees. That is, a UE may report a series of RSRP values, and the positioning entity may determine the location of the UE in the azimuth domain based on where the reported RSRP measurements line up with the beam responses of the measured downlink transmit beams (e.g., −20 degrees in FIG. **11**).

[0115] As such, the positioning entity needs to know the beam responses of the downlink transmit beams in order to determine the point on the beam responses that corresponds to the measured RSRPs. Different options have been proposed to report the beam responses of the downlink transmit beams (referred to as "beam shape assistance information") to the positioning entity. As a first option, the base station may report $\{P_k\}_{k=1}^{N}$ for each possible angle, where P is the expected receive power (e.g., RSRP), N is the number of angles, and k is an angle index. Specifically, the base station may report a list of angles (AoDs and/or AoAs, or zeniths of departure (ZoDs) and/or zeniths of arrival (ZoAs), or a combination of AoDs and/or AoAs and ZoDs and/or ZoAs). For each angle, the base station may report a list of PRS resource identifiers and a list of radiation powers (densities) at the angle, each of which is associated with a PRS resource identifier. As a second option, the base station may report the beam response of each PRS resource across AoD and/or ZoD. Specifically, the base station may report a list of PRS resource identifiers. For each PRS resource identifier, the base station may report a list of angles (AoDs and/or AoAs, or ZoDs and/or ZoAs, or a combination of AoDs and/or AoAs and ZoDs and/or ZoAs) and a list of radiation powers (densities) of the PRS resource, each of which is associated with the angle.

[0116] Various frame structures may be used to support downlink and uplink transmissions between network nodes (e.g., base stations and UEs). FIG. **12**A is a diagram **1200** illustrating an example of a downlink frame structure, according to aspects of the disclosure. FIG. **12**B is a diagram **1230** illustrating an example of channels within the downlink frame structure, according to aspects of the disclosure. FIG. **12**C is a diagram **1250** illustrating an example of an uplink frame structure, according to aspects of the disclosure. FIG. **12**D is a diagram **1280** illustrating an example of channels within an uplink frame structure, according to aspects of the disclosure. Other wireless communications technologies may have different frame structures and/or different channels.

[0117] LTE, and in some cases NR, utilizes OFDM on the downlink and single-carrier frequency division multiplexing (SC-FDM) on the uplink. Unlike LTE, however, NR has an option to use OFDM on the uplink as well. OFDM and SC-FDM partition the system bandwidth into multiple (K) orthogonal subcarriers, which are also commonly referred to as tones, bins, etc. Each subcarrier may be modulated with data. In general, modulation symbols are sent in the frequency domain with OFDM and in the time domain with SC-FDM. The spacing between adjacent subcarriers may be fixed, and the total number of subcarriers (K) may be

dependent on the system bandwidth. For example, the spacing of the subcarriers may be 15 kilohertz (kHz) and the minimum resource allocation (resource block) may be 12 subcarriers (or 180 kHz). Consequently, the nominal FFT size may be equal to 128, 256, 512, 1024, or 2048 for system bandwidth of 1.25, 2.5, 5, 10, or 20 megahertz (MHz), respectively. The system bandwidth may also be partitioned into subbands. For example, a subband may cover 1.08 MHz (i.e., **6** resource blocks), and there may be 1, 2, 4, 8, or 16 subbands for system bandwidth of 1.25, 2.5, 5, 10, or 20 MHz, respectively.

[0118] LTE supports a single numerology (subcarrier spacing (SCS), symbol length, etc.). In contrast, NR may support multiple numerologies (μ), for example, subcarrier spacings of 15 kHz (μ=0), 30 kHz (μ=1), 60 kHz (μ=2), 120 kHz (μ=3), and 240 kHz (μ=4) or greater may be available. In each subcarrier spacing, there are 14 symbols per slot. For 15 kHz SCS (μμ0), there is one slot per subframe, 10 slots per frame, the slot duration is 1 millisecond (ms), the symbol duration is 66.7 microseconds (μs), and the maximum nominal system bandwidth (in MHz) with a 4K FFT size is 50. For 30 kHz SCS (μ=1), there are two slots per subframe, 20 slots per frame, the slot duration is 0.5 ms, the symbol duration is 33.3 μs, and the maximum nominal system bandwidth (in MHz) with a 4K FFT size is 100. For 60 kHz SCS (μ=2), there are four slots per subframe, 40 slots per frame, the slot duration is 0.25 ms, the symbol duration is 16.7 μs, and the maximum nominal system bandwidth (in MHz) with a 4K FFT size is 200. For 120 kHz SCS (μ=3), there are eight slots per subframe, 80 slots per frame, the slot duration is 0.125 ms, the symbol duration is 8.33 μs, and the maximum nominal system bandwidth (in MHz) with a 4K FFT size is 400. For 240 kHz SCS (μ=4), there are 16 slots per subframe, 160 slots per frame, the slot duration is 0.0625 ms, the symbol duration is 4.17 μs, and the maximum nominal system bandwidth (in MHz) with a 4K FFT size is 800.

[0119] In the example of FIGS. **12**A to **12**D, a numerology of 15 kHz is used. Thus, in the time domain, a 10 ms frame is divided into 10 equally sized subframes of 1 ms each, and each subframe includes one time slot. In FIGS. **12**A to **12**D, time is represented horizontally (on the X axis) with time increasing from left to right, while frequency is represented vertically (on the Y axis) with frequency increasing (or decreasing) from bottom to top.

[0120] A resource grid may be used to represent time slots, each time slot including one or more time-concurrent resource blocks (RBs) (also referred to as physical RBs (PRBs)) in the frequency domain. The resource grid is further divided into multiple resource elements (REs). An RE may correspond to one symbol length in the time domain and one subcarrier in the frequency domain. In the numerology of FIGS. **12**A to **12**D, for a normal cyclic prefix, an RB may contain 12 consecutive subcarriers in the frequency domain and seven consecutive symbols in the time domain, for a total of 84 REs. For an extended cyclic prefix, an RB may contain 12 consecutive subcarriers in the frequency domain and six consecutive symbols in the time domain, for a total of 72 REs. The number of bits carried by each RE depends on the modulation scheme.

[0121] Some of the REs carry downlink reference (pilot) signals (DL-RS). The DL-RS may include PRS, TRS, PTRS, CRS, CSI-RS, DMRS, PSS, SSS, SSB, etc. FIG. **12**A illustrates example locations of REs carrying PRS (labeled "R").

[0122] A collection of resource elements (REs) that are used for transmission of PRS is referred to as a "PRS resource." The collection of resource elements can span multiple PRBs in the frequency domain and 'N' (such as 1 or more) consecutive symbol(s) within a slot in the time domain. In a given OFDM symbol in the time domain, a PRS resource occupies consecutive PRBs in the frequency domain.

[0123] The transmission of a PRS resource within a given PRB has a particular comb size (also referred to as the "comb density"). A comb size 'N' represents the subcarrier spacing (or frequency/tone spacing) within each symbol of a PRS resource configuration. Specifically, for a comb size 'N,' PRS are transmitted in every Nth subcarrier of a symbol of a PRB. For example, for comb-4, for each symbol of the PRS resource configuration, REs corresponding to every fourth subcarrier (such as subcarriers 0, 4, 8) are used to transmit PRS of the PRS resource. Currently, comb sizes of comb-2, comb-4, comb-6, and comb-12 are supported for DL-PRS. FIG. **12**A illustrates an example PRS resource configuration for comb-6 (which spans six symbols). That is, the locations of the shaded REs (labeled "R") indicate a comb-6 PRS resource configuration.

[0124] Currently, a DL-PRS resource may span 2, 4, 6, or 12 consecutive symbols within a slot with a fully frequency-domain staggered pattern. A DL-PRS resource can be configured in any higher layer configured downlink or flexible (FL) symbol of a slot. There may be a constant energy per resource element (EPRE) for all REs of a given DL-PRS resource. The following are the frequency offsets from symbol to symbol for comb sizes 2, 4, 6, and 12 over 2, 4, 6, and 12 symbols. 2-symbol comb-2: {0, 1}; 4-symbol comb-2: {0, 1, 0, 1}; 6-symbol comb-2: {0, 1, 0, 1, 0, 1}; 12-symbol comb-2: {0, 1, 0, 1, 0, 1, 0, 1, 0, 1, 0, 1}; 4-symbol comb-4: {0, 2, 1, 3}; 12-symbol comb-4: {0, 2, 1, 3, 0, 2, 1, 3, 0, 2, 1, 3}; 6-symbol comb-6: {0, 3, 1, 4, 2, 5}; 12-symbol comb-6: {0, 3, 1, 4, 2, 5, 0, 3, 1, 4, 2, 5}; and 12-symbol comb-12: {0, 6, 3, 9, 1, 7, 4, 10, 2, 8, 5, 11}.

[0125] A "PRS resource set" is a set of PRS resources used for the transmission of PRS signals, where each PRS resource has a PRS resource ID. In addition, the PRS resources in a PRS resource set are associated with the same TRP. A PRS resource set is identified by a PRS resource set ID and is associated with a particular TRP (identified by a TRP ID). In addition, the PRS resources in a PRS resource set have the same periodicity, a common muting pattern configuration, and the same repetition factor (such as "PRS-ResourceRepetitionFactor") across slots. The periodicity is the time from the first repetition of the first PRS resource of a first PRS instance to the same first repetition of the same first PRS resource of the next PRS instance. The periodicity may have a length selected from 2^μ*{4, 5, 8, 10, 16, 20, 32, 40, 64, 80, 160, 320, 640, 1280, 2560, 5120, 10240} slots, with μ=0, 1, 2, 3. The repetition factor may have a length selected from {1, 2, 4, 6, 8, 16, 32} slots.

[0126] A PRS resource ID in a PRS resource set is associated with a single beam (or beam ID) transmitted from a single TRP (where a TRP may transmit one or more beams). That is, each PRS resource of a PRS resource set may be transmitted on a different beam, and as such, a "PRS resource," or simply "resource," also can be referred to as a

"beam." Note that this does not have any implications on whether the TRPs and the beams on which PRS are transmitted are known to the UE.

[0127] A "PRS instance" or "PRS occasion" is one instance of a periodically repeated time window (such as a group of one or more consecutive slots) where PRS are expected to be transmitted. A PRS occasion also may be referred to as a "PRS positioning occasion," a "PRS positioning instance, a "positioning occasion," "a positioning instance," a "positioning repetition," or simply an "occasion," an "instance," or a "repetition."

[0128] A "positioning frequency layer" (also referred to simply as a "frequency layer") is a collection of one or more PRS resource sets across one or more TRPs that have the same values for certain parameters. Specifically, the collection of PRS resource sets has the same subcarrier spacing and cyclic prefix (CP) type (meaning all numerologies supported for the PDSCH are also supported for PRS), the same Point A, the same value of the downlink PRS bandwidth, the same start PRB (and center frequency), and the same comb-size. The Point A parameter takes the value of the parameter "ARFCN-ValueNR" (where "ARFCN" stands for "absolute radio-frequency channel number") and is an identifier/code that specifies a pair of physical radio channel used for transmission and reception. The downlink PRS bandwidth may have a granularity of four PRBs, with a minimum of 24 PRBs and a maximum of 272 PRBs. Currently, up to four frequency layers have been defined, and up to two PRS resource sets may be configured per TRP per frequency layer.

[0129] The concept of a frequency layer is somewhat like the concept of component carriers and bandwidth parts (BWPs), but different in that component carriers and BWPs are used by one base station (or a macro cell base station and a small cell base station) to transmit data channels, while frequency layers are used by several (usually three or more) base stations to transmit PRS. A UE may indicate the number of frequency layers it can support when it sends the network its positioning capabilities, such as during an LTE positioning protocol (LPP) session. For example, a UE may indicate whether it can support one or four positioning frequency layers.

[0130] FIG. **12**B illustrates an example of various channels within a downlink slot of a radio frame. In NR, the channel bandwidth, or system bandwidth, is divided into multiple BWPs. A BWP is a contiguous set of PRBs selected from a contiguous subset of the common RBs for a given numerology on a given carrier. Generally, a maximum of four BWPs can be specified in the downlink and uplink. That is, a UE can be configured with up to four BWPs on the downlink, and up to four BWPs on the uplink. Only one BWP (uplink or downlink) may be active at a given time, meaning the UE may only receive or transmit over one BWP at a time. On the downlink, the bandwidth of each BWP should be equal to or greater than the bandwidth of the SSB, but it may or may not contain the SSB.

[0131] Referring to FIG. **12**B, a primary synchronization signal (PSS) is used by a UE to determine subframe/symbol timing and a physical layer identity. A secondary synchronization signal (SSS) is used by a UE to determine a physical layer cell identity group number and radio frame timing. Based on the physical layer identity and the physical layer cell identity group number, the UE can determine a PCI. Based on the PCI, the UE can determine the locations of the aforementioned DL-RS. The physical broadcast channel (PBCH), which carries an MIB, may be logically grouped with the PSS and SSS to form an SSB (also referred to as an SS/PBCH). The MIB provides a number of RBs in the downlink system bandwidth and a system frame number (SFN). The physical downlink shared channel (PDSCH) carries user data, broadcast system information not transmitted through the PBCH, such as system information blocks (SIBs), and paging messages.

[0132] The physical downlink control channel (PDCCH) carries downlink control information (DCI) within one or more control channel elements (CCEs), each CCE including one or more RE group (REG) bundles (which may span multiple symbols in the time domain), each REG bundle including one or more REGs, each REG corresponding to 12 resource elements (one resource block) in the frequency domain and one OFDM symbol in the time domain. The set of physical resources used to carry the PDCCH/DCI is referred to in NR as the control resource set (CORESET). In NR, a PDCCH is confined to a single CORESET and is transmitted with its own DMRS. This enables UE-specific beamforming for the PDCCH.

[0133] In the example of FIG. **12**B, there is one CORESET per BWP, and the CORESET spans three symbols (although it may be only one or two symbols) in the time domain. Unlike LTE control channels, which occupy the entire system bandwidth, in NR, PDCCH channels are localized to a specific region in the frequency domain (i.e., a CORESET). Thus, the frequency component of the PDCCH shown in FIG. **12**B is illustrated as less than a single BWP in the frequency domain. Note that although the illustrated CORESET is contiguous in the frequency domain, it need not be. In addition, the CORESET may span less than three symbols in the time domain.

[0134] The DCI within the PDCCH carries information about uplink resource allocation (persistent and non-persistent) and descriptions about downlink data transmitted to the UE, referred to as uplink and downlink grants, respectively. More specifically, the DCI indicates the resources scheduled for the downlink data channel (e.g., PDSCH) and the uplink data channel (e.g., PUSCH). Multiple (e.g., up to eight) DCIs can be configured in the PDCCH, and these DCIs can have one of multiple formats. For example, there are different DCI formats for uplink scheduling, for downlink scheduling, for uplink transmit power control (TPC), etc. A PDCCH may be transported by 1, 2, 4, 8, or 16 CCEs in order to accommodate different DCI payload sizes or coding rates.

[0135] As illustrated in FIG. **12**C, some of the REs (labeled "R") carry DMRS for channel estimation at the receiver (e.g., a base station, another UE, etc.). A UE may additionally transmit SRS in, for example, the last symbol of a slot. The SRS may have a comb structure, and a UE may transmit SRS on one of the combs. In the example of FIG. **12**C, the illustrated SRS is comb-2 over one symbol. The SRS may be used by a base station to obtain the channel state information (CSI) for each UE. CSI describes how an RF signal propagates from the UE to the base station and represents the combined effect of scattering, fading, and power decay with distance. The system uses the SRS for resource scheduling, link adaptation, massive MIMO, beam management, etc.

[0136] Currently, an SRS resource may span 1, 2, 4, 8, or 12 consecutive symbols within a slot with a comb size of

comb-2, comb-4, or comb-8. The following are the frequency offsets from symbol to symbol for the SRS comb patterns that are currently supported. 1-symbol comb-2: {0}; 2-symbol comb-2: {0, 1}; 4-symbol comb-2: {0, 1, 0, 1}; 4-symbol comb-4: {0, 2, 1, 3}; 8-symbol comb-4: {0, 2, 1, 3, 0, 2, 1, 3}; 12-symbol comb-4: {0, 2, 1, 3, 0, 2, 1, 3, 0, 2, 1, 3}; 4-symbol comb-8: {0, 4, 2, 6}; 8-symbol comb-8: {0, 4, 2, 6, 1, 5, 3, 7}; and 12-symbol comb-8: {0, 4, 2, 6, 1, 5, 3, 7, 0, 4, 2, 6}.

[0137] A collection of resource elements that are used for transmission of SRS is referred to as an "SRS resource," and may be identified by the parameter "SRS-ResourceId." The collection of resource elements can span multiple PRBs in the frequency domain and N (e.g., one or more) consecutive symbol(s) within a slot in the time domain. In a given OFDM symbol, an SRS resource occupies consecutive PRBs. An "SRS resource set" is a set of SRS resources used for the transmission of SRS signals, and is identified by an SRS resource set ID ("SRS-ResourceSetId").

[0138] Generally, a UE transmits SRS to enable the receiving base station (either the serving base station or a neighboring base station) to measure the channel quality between the UE and the base station. However, SRS can also be specifically configured as uplink positioning reference signals for uplink-based positioning procedures, such as uplink time difference of arrival (UL-TDOA), round-trip-time (RTT), uplink angle-of-arrival (UL-AoA), etc. As used herein, the term "SRS" may refer to SRS configured for channel quality measurements or SRS configured for positioning purposes. The former may be referred to herein as "SRS-for-communication" and/or the latter may be referred to as "SRS-for-positioning" when needed to distinguish the two types of SRS.

[0139] Several enhancements over the previous definition of SRS have been proposed for SRS-for-positioning (also referred to as "UL-PRS"), such as a new staggered pattern within an SRS resource (except for single-symbol/comb-2), a new comb type for SRS, new sequences for SRS, a higher number of SRS resource sets per component carrier, and a higher number of SRS resources per component carrier. In addition, the parameters "SpatialRelationInfo" and "PathLossReference" are to be configured based on a downlink reference signal or SSB from a neighboring TRP. Further still, one SRS resource may be transmitted outside the active BWP, and one SRS resource may span across multiple component carriers. Also, SRS may be configured in RRC connected state and only transmitted within an active BWP. Further, there may be no frequency hopping, no repetition factor, a single antenna port, and new lengths for SRS (e.g., 8 and 12 symbols). There also may be open-loop power control and not closed-loop power control, and comb-8 (i.e., an SRS transmitted every eighth subcarrier in the same symbol) may be used. Lastly, the UE may transmit through the same transmit beam from multiple SRS resources for UL-AoA. All of these are features that are additional to the current SRS framework, which is configured through RRC higher layer signaling (and potentially triggered or activated through MAC control element (CE) or DCI).

[0140] FIG. **12**D illustrates an example of various channels within an uplink slot of a frame, according to aspects of the disclosure. A random-access channel (RACH), also referred to as a physical random-access channel (PRACH), may be within one or more slots within a frame based on the PRACH configuration. The PRACH may include six consecutive RB pairs within a slot. The PRACH allows the UE to perform initial system access and achieve uplink synchronization. A physical uplink control channel (PUCCH) may be located on edges of the uplink system bandwidth. The PUCCH carries uplink control information (UCI), such as scheduling requests, CSI reports, a channel quality indicator (CQI), a precoding matrix indicator (PMI), a rank indicator (RI), and HARQ ACK/NACK feedback. The physical uplink shared channel (PUSCH) carries data, and may additionally be used to carry a buffer status report (BSR), a power headroom report (PHR), and/or UCI.

[0141] Note that the terms "positioning reference signal" and "PRS" generally refer to specific reference signals that are used for positioning in NR and LTE systems. However, as used herein, the terms "positioning reference signal" and "PRS" may also refer to any type of reference signal that can be used for positioning, such as but not limited to, PRS as defined in LTE and NR, TRS, PTRS, CRS, CSI-RS, DMRS, PSS, SSS, SSB, SRS, UL-PRS, etc. In addition, the terms "positioning reference signal" and "PRS" may refer to downlink or uplink positioning reference signals, unless otherwise indicated by the context. If needed to further distinguish the type of PRS, a downlink positioning reference signal may be referred to as a "DL-PRS," and an uplink positioning reference signal (e.g., an SRS-for-positioning, PTRS) may be referred to as an "UL-PRS." In addition, for signals that may be transmitted in both the uplink and downlink (e.g., DMRS, PTRS), the signals may be prepended with "UL" or "DL" to distinguish the direction. For example, "UL-DMRS" may be differentiated from "DL-DMRS."

[0142] FIG. **13** is a diagram of an example PRS configuration **1300** for the PRS transmissions of a given base station, according to aspects of the disclosure. In FIG. **13**, time is represented horizontally, increasing from left to right. Each long rectangle represents a slot and each short (shaded) rectangle represents an OFDM symbol. In the example of FIG. **13**, a PRS resource set **1310** (labeled "PRS resource set **1**") includes two PRS resources, a first PRS resource **1312** (labeled "PRS resource **1**") and a second PRS resource **514** (labeled "PRS resource **2**"). The base station transmits PRS on the PRS resources **1312** and **1314** of the PRS resource set **1310**.

[0143] The PRS resource set **1310** has an occasion length (N_PRS) of two slots and a periodicity (T_PRS) of, for example, 160 slots or 160 milliseconds (ms) (for 15 kHz subcarrier spacing). As such, both the PRS resources **1312** and **1314** are two consecutive slots in length and repeat every T_PRS slots, starting from the slot in which the first symbol of the respective PRS resource occurs. In the example of FIG. **13**, the PRS resource **1312** has a symbol length (N_symb) of two symbols, and the PRS resource **1314** has a symbol length (N_symb) of four symbols. The PRS resource **1312** and the PRS resource **1314** may be transmitted on separate beams of the same base station.

[0144] Each instance of the PRS resource set **1310**, illustrated as instances **1320***a*, **1320***b*, and **1320***c*, includes an occasion of length '2' (i.e., N_PRS=2) for each PRS resource **1312**, **1314** of the PRS resource set. The PRS resources **1312** and **1314** are repeated every T_PRS slots up to the muting sequence periodicity T_REP. As such, a bitmap of length T_REP would be needed to indicate which occasions of instances **1320***a*, **1320***b*, and **1320***c* of PRS resource set **610** are muted (i.e., not transmitted).

[0145] In an aspect, there may be additional constraints on the PRS configuration **1300**. For example, for all PRS resources (e.g., PRS resources **1312**, **1314**) of a PRS resource set (e.g., PRS resource set **1310**), the base station can configure the following parameters to be the same: (a) the occasion length (T_PRS), (b) the number of symbols (N_symb), (c) the comb type, and/or (d) the bandwidth. In addition, for all PRS resources of all PRS resource sets, the subcarrier spacing and the cyclic prefix can be configured to be the same for one base station or for all base stations. Whether it is for one base station or all base stations may depend on the UE's capability to support the first and/or second option.

[0146] NR positioning techniques are expected to provide high accuracy (horizontal and vertical), low latency, network efficiency (scalability, reference signal overhead, etc.), and device efficiency (power consumption, complexity, etc.), especially for commercial positioning uses cases (including general commercial use cases and specifically (I)IoT use cases). Referring to the accuracy expectation, the accuracy of a location estimate depends on the accuracy of the positioning measurements (e.g., ToA, RSTD, Rx-Tx, etc.) of received PRS, and the larger the bandwidth of the measured PRS, the more accurate the positioning measurements.

[0147] One technique for increasing the bandwidth of PRS is aggregating PRS across the frequency domain (referred to as "frequency domain stitching") and/or the time domain (referred to as "time domain stitching"). In frequency domain PRS stitching, PRS are transmitted (by a base station or UE) on multiple, preferably contiguous, bandwidth intervals (e.g., positioning frequency layers, bandwidth parts (BWPs), groups of contiguous PRBs, etc.) within one or more component carriers, frequency bands, or other portions of bandwidth, and the receiver (a UE or base station) measures the PRS across the (contiguous) bandwidth intervals. By spanning multiple bandwidth intervals, the effective bandwidth of the PRS is increased, resulting in increased positioning measurement accuracy. In time domain PRS stitching, the multiple bandwidth intervals also span multiple, preferably contiguous, time intervals (e.g., groups of contiguous symbols, slots, subframes, etc.). When implementing time and/or frequency domain PRS stitching, the PRS should preferably be transmitted on multiple bandwidth intervals and/or time intervals such that the receiver can make certain assumptions about the PRS transmitted within the multiple slots and/or positioning frequency layers (e.g., QCL type, same antenna port, etc.).

[0148] FIG. **14** is a diagram **1400** of an example of frequency domain PRS stitching, according to aspects of the disclosure. As shown in FIG. **14**, PRS **1410-1**, **1410-2**, and **1410-3** (labeled "PRS1," "PRS2," and "PRS3," respectively) are transmitted on respective positioning frequency layers (labeled "PFL1," "PFL2," and "PFL3," respectively) within a given frequency band (labeled "B1"). The frequency band "B1" may be a frequency band in FR1 or FR2. The PRS **1410** may be DL-PRS transmitted by a base station to one or more UEs, UL-PRS transmitted by a UE to one or more base stations, or sidelink PRS transmitted by a UE to one or more other UEs.

[0149] In FIG. **14**, time is represented horizontally and frequency is represented vertically. Thus, in the example of FIG. **14**, the three positioning frequency layers are contiguous in the frequency domain. Although FIG. **14** illustrates a single frequency band "B1," the positioning frequency layers may instead span multiple frequency bands (possibly in both FR1 and FR2), with or without a guard band between the different frequency bands. Further, the positioning frequency layers may span one or more component carriers within the one or more frequency bands. In addition, while FIG. **14** illustrates PRS **1410** transmitted on three positioning frequency layers, as will be appreciated, PRS **1410** may be transmitted on only two positioning frequency layers or on more than three positioning frequency layers.

[0150] In the time domain, the PRS **1410** may be PRS occasions, PRS resources, slots containing PRS, etc. The PRS **1410** should generally be identical to each other except that they are transmitted on different positioning frequency layers. However, while the PRS **1410** in FIG. **14** are illustrated as beginning and ending at the same time, this may not always be the case, and some PRS **1410** may begin or end or have a different length than other PRS **1410**.

[0151] Using different positioning frequency layers (especially across different component carriers or frequency bands) for the transmission and reception of the PRS **1410** introduces the issue of phase shift between the waveforms carrying the different PRS **1410**. Phase shift is the difference in phase, or phase difference, between two waveforms. Thus, for example, the phase of the waveform of PRS **1410-2** may be slightly different than the phase of the waveform of PRS **1410-1**. Mathematically, the channel on which a first PRS (e.g., PRS **1410-1**) is transmitted can be represented as h(f,t1), where f represents frequency, t1 represents time, and h represents the channel as a function of frequency f and time t1. The channel on which a related PRS (e.g., a PRS to be stitched together with the first PRS, such as PRS **1410-2**) is transmitted can be represented as $h(f,t1)\cdot e^{j\theta}$, where $e^{j\theta}$ represents the phase shift, or phase difference, between the channel on which the first PRS is transmitted and the channel on which the related PRS is transmitted.

[0152] Phase shift can occur in both intra- and inter-band PRS (i.e., PRS on positioning frequency layers within the same component carrier or frequency band or PRS on positioning frequency layers within multiple component carriers or frequency bands). Phase shift is particularly noticeable when two signals (waveforms) are combined together by a physical process, such as by a receiver's analog front-end. However, phase shift can be caused by the architecture of both the transmitter and receiver. For example, any change in the transmit/receive RF chain may cause discontinuity in the phase of the PRS **1410**. A phase shift between the waveforms of PRS transmitted on multiple positioning frequency layers can cause additional measurement errors in the measurement estimation procedure (e.g., ToA estimation procedure), which lowers the positioning accuracy.

[0153] Given an antenna array with fixed spacing, different carrier frequencies (CFs) may be associated with a phenomenon known as "beam squint" (e.g., different beam shapes or beam directions). Array gain distribution as a function of spatial angles (e.g., beam pattern/shape) generally drifts with frequency due to beam squint effects (e.g., use of fixed inter-element spacings for ultra-wideband coverage). Positioning using a fixed set of beam weights at a certain CF can correspond to a certain AoD/AoA estimate at that frequency. However, the same beam weight may correspond to a different AoD/AoA estimate at a different CF. This problem can be generalized to bandwidth part (BWP)

or component carrier (CC) or PFL (e.g., frequency layer, e.g., at 57 GHZ, 61 GHz and/or 71 GHz). In FR2, CFs may correspond to 28 GHz or 39 GHz, BW may be 400 MHz or 800 MHz+(with PRS band-stitching). In FR2x, CFs may range from 52.6 GHz to 71 GHz, and BW may be 2 GHz+. The beam squint problem also impacts FR1 based positioning if PRS bandwidth stitching (with multiple PFLs) is enabled. Hence, RSRP measurements may be different across different CFs, which results in different AoD measurements for the different CFs.

[0154] In general, the ratio of BW/CF may provide a rough estimation of beam squint. In some designs, beam squint assistance information related to the antenna configuration and a beam weight (e.g., pattern/shape) may be defined as a function of CF/BWP or BWP/CF. This assistance information may be sent by gNB to LMF (or other position estimation entity) and used for position estimation. Alternatively, RSRPs may be measured with respect to multiple PRS resources. However, in legacy systems, only one RSRP is measured per PRS resource.

[0155] One problem in such legacy systems is that the PRS spans a wide bandwidth, such as two (or more) PFLs. With beam squint an expected RSRP signature given certain AoD is different across PFLs because the beam shape is different. FIG. **15** illustrates graphs depicting an example beam response of different PRS resources in the azimuth domain, according to aspects of the disclosure. In particular, graph **1500** depicts the beam response for PFL1, and graph **1550** depicts the beam response for PFL2. In particular, the graph **1550** shows the impact of the beam response due to beam squint. As noted above, legacy systems may simply measure a single RSRP per PRS resource, which does not account for the effect due to beam squint between sub-bands of the PRS resource as shown in the graph **1550**.

[0156] For example, with respect to FIG. **15**, assume that the expected RSRP signature in PFL1 is [1 2 3 2 1] (e.g., assume 5 PRS resources), and the expected RSRP signature in PFL2 is [1 12 3 2] (e.g., the beam squint in effect shifts the beam response forward). If the UE only measures one RSRP across two PFLs per PRS resource, then it is compared with a combined expected RSRP signature (e.g., 0.5*[1 2 3 2 1]+0.5*[1 1 2 3 2]). In this case, the RSRP signature is lose due to the averaging effect, and the true RSRP in the two PFLs is not reported to the position estimation entity.

[0157] Aspects of the disclosure are directed to measurement report with measurement indications for multiple sub-bands of a reference signal for positioning resource. Such measurements may include RSRP as noted above, but may also (or alternatively) include timing measurements. Also, such measurements may relate to DL-PRS as noted above, but may apply to other reference signal for positioning (RS-P) types, such as sidelink PRS, uplink sounding reference signal for positioning (UL-SRS-P), and so on. Such aspects may provide various technical advantages, such as improved positioning accuracy (e.g., because beam squint may be better compensated for at the position estimation entity).

[0158] FIG. **16** illustrates an exemplary process **1600** of wireless communication, according to aspects of the disclosure. In an aspect, the process **1560** may be performed by a wireless node, such as UE **302** (e.g., a target UE for which a positioning estimate is desired, an anchor or reference UE with a known position from a recent positioning fix, etc.) or BS **304** (e.g., a serving or non-serving gNB).

[0159] Referring to FIG. **16**, at **1610**, the wireless node (e.g., receiver **312** or **322** or **352** or **362**, positioning component **332** or **388**, processing system **332** or **384**, etc.) performs a first measurement of a RS-P on a first sub-band of a plurality of sub-bands associated with an RS-P resource. As will be described below in more detail, the RS-P may correspond to DL or SL PRS, UL-SRS-P, etc. In some designs, the RS-P may also correspond to a stitched RS-P (e.g., a frequency stitched PRS or SRS, a time stitched PRS or SRS, etc.). Also, the first measurement can correspond to any of various measurement types, including but not limited to RSRP or a timing measurement such as TOA, TDOA or RSTD.

[0160] Referring to FIG. **16**, at **1620**, the wireless node (e.g., receiver **312** or **322** or **352** or **362**, positioning component **332** or **388**, processing system **332** or **384**, etc.) performs a second measurement of the RS-P on a second sub-band of the plurality of sub-bands associated with the RS-P resource. In some designs, the first and second measurements are of the same measurement type (e.g., both RSRP, or both TOA, TDOA or RSTD, etc.). In some designs, the first and second sub-bands may be spaced apart across the RS-P resource in terms of frequency.

[0161] Referring to FIG. **16**, at **1630**, the wireless node (e.g., transmitter **314** or **324** or **354** or **364**, data bus **334** or **382**, or network interface(s) **380**, etc.) transmits, to a position estimation entity in association with a positioning session of a UE, a measurement report comprising a first indication of the first measurement and a second indication of the second measurement.

[0162] FIG. **17** illustrates an exemplary process **1700** of communications according to an aspect of the disclosure. The process **1700** of FIG. **17** is performed by a position estimation entity, which may correspond to UE **302** (e.g., a target UE for which a positioning fix is desired, a relay, anchor or reference UE associated with a known location, e.g., from a recent positioning fix), or BS **304** (e.g., a serving gNB), a location management function (LMF), a location server, or a combination thereof.

[0163] Referring to FIG. **17**, at **1710**, the position estimation entity (e.g., receiver **312** or **322** or **352** or **362**, network interface(s) **380** or **390**, data bus **334** or **382**, etc.) receives, from a wireless node in association with a positioning session of a UE, a measurement report comprising a first indication of a first measurement of an RS-P on a first sub-band of a plurality of sub-bands associated with an RS-P resource, and a second indication of a second measurement of the RS-P on a second sub-band of the plurality of sub-bands associated with the RS-P resource. As will be described below in more detail, the RS-P may correspond to DL or SL PRS, UL-SRS-P, etc. Also, the first measurement can correspond to any of various measurement types, including but not limited to RSRP or a timing measurement such as TOA, TDOA or RSTD. In some designs, the first and second measurements are of the same measurement type (e.g., both RSRP, or both TOA, TDOA or RSTD, etc.). In some designs, the first and second sub-bands may be spaced apart across the RS-P resource in terms of frequency.

[0164] Referring to FIG. **17**, at **1720**, the position estimation entity (e.g., positioning module **342** or **388** or **398**,

processing system **332** or **388** or **398**, etc.) determines a positioning estimate of the UE based in part on the measurement report.

[0165] Referring to FIGS. **16-17**, in some designs, the first and second sub-bands are separated in frequency by at least one intervening sub-band. FIG. **18** illustrates a sub-band arrangement for a PRS resource **1800** in accordance with an aspect of the disclosure. In FIG. **18**, the PRS resource **1800** includes a first sub-band **1802**, a second sub-band **1804** and an intervening sub-band region **1806**. The wireless node may perform the first and second measurements (e.g., RSRPs) on the sub-bands **1804-1806**, while refraining from measuring the intervening sub-band region **1806**. For example, the separation of the intervening sub-band region **1806** may provide a diversity of angle measurements. FIG. **19** illustrates a sub-band arrangement for a PRS resource **1900** in accordance with another aspect of the disclosure. In FIG. **19**, the PRS resource **1900** includes sub-bands **1902** **1904**, **1906** and **1908**, with intervening sub-band regions **1910-1**, **1910-2** and **1910-3**. The wireless node may perform measurements (e.g., RSRPs) on each of the sub-bands **1902-1908**, while refraining from measuring the intervening sub-band regions **1910-1**, **1910-2** and **1910-3**.

[0166] Referring to FIGS. **16-17**, in some designs, the first measurement, the second measurement, or both, comprise a reference signal received power (RSRP) measurement, a timing measurement, or a combination thereof.

[0167] Referring to FIGS. **16-17**, in some designs, the wireless node corresponds to a UE (e.g., a target UE for which a positioning estimate is desired that is measuring DL-PRS or sidelink PRS from an anchor or reference UE, or the anchor or reference UE measuring UL-SRS-P from the target UE). In one example, the positioning session is UE-assisted, and the position estimation entity corresponds to an LMF (e.g., measurement report is transmitted to LMF). In another example, the positioning session is UE-based such that the position estimation entity corresponds to the UE, and the measurement report is transmitted via transfer between logical components of the UE.

[0168] Referring to FIGS. **16-17**, in some designs, the wireless node corresponds to a base station (e.g., a serving or non-serving gNB). In some designs, the positioning session is UE-assisted, and the position estimation entity corresponds to an LMF (e.g., measurement report is transmitted to LMF, either logically if LMF integrated in RAN or via backhaul link to remote LMF). Accordingly, the position estimation entity may correspond to a UE (e.g., target UE, reference UE or anchor UE), a base station, a location management function, or a combination thereof.

[0169] Referring to FIGS. **16-17**, in some designs, the position estimation entity may transmit a report configuration associated with the measurement report. In some designs, the report configuration indicates a list of sub-bands (e.g., to be measured or at least to be considered for potential measurement).

[0170] In an example, each sub-band in the list of sub-bands is specified by:

[0171] a start point of the RS-P resource and an end-point of the RS-P resource, or

[0172] a start point of the RS-P resource along with an offset (e.g., in resource blocks (RBs) in tones, etc.), or

[0173] a start point of the RS-P resource along with an absolute bandwidth (BW), or

[0174] a start point of the RS-P resource along with an a BW relative to the RS-P, or

[0175] a start tone and end tone, or

[0176] a sub-band indicator associated with an indicator list of RS-P resources or RS-P blocks within stitched RS-P resources (e.g., this applies for PRS carrier aggregation case where multiple PRS-resources or blocks are stitched together for timing measurement), or

[0177] a sub-band indicator associated with an indicator list of sub-bands associated with New Radio Unlicensed (NRU) spectrum (e.g., in the NRU, the unlicensed spectrum is shared by different devices. The PRS may spans over multiple subbands, and certain subband may not be available at certain time), or

[0178] a number of sub-bands per RS-P (e.g., equally divide the BW of PRS into X sub-bands, which implicitly specifies the locations of the list of sub-bands), or

[0179] a combination thereof.

[0180] In some designs, an ID may be added for each sub-band in the report configuration. In some designs, the list of sub-bands may include one or more recommended or non-recommended sub-bands for measurement, one or more requested or non-requested sub-bands for measurement, a priority or ranking of sub-bands for measurement within the list of sub-bands, or a combination thereof. So, the list of sub-bands can be inclusive or exclusive in terms of measurement consideration by the wireless node. Moreover, there may be some flexibility in terms of which sub-band(s) are measured and/or reported at the wireless node. In some designs, the UE may report measurements for only a subset (e.g., less than all) of the sub-bands in the list of sub-bands.

[0181] In one example implementation of the processes **1600-1700** of FIGS. **16-17**, for UE-assisted positioning, the LMF may send DL-AoD report configuration to UE and UL-AoA report configuration to gNBs. The respective report configurations may include assistance data related to RSRP "vector" reports (e.g., multiple measurements per PRS resource, which in some designs may be associated with a stitched RS-P, such as a frequency stitched PRS or SRS, a time stitched PRS or SRS, etc.). The UE measures multiple RSRPs of different subbands with different PRS-resources in DL-AoD, which are reported to LMF. The gNB(s) measure multiple RSRPs of different sub-bands with different PRS-resources in UL-AoA, which are reported to LMF.

[0182] In another example implementation of the processes **1600-1700** of FIGS. **16-17**, for UE-based positioning, the LMF sends UL-AoA (report) config to gNBs. In the configuration, assistance data is added about the details about RSRP vector reports. For DL-AoD, UE may estimate AoD by itself. For UL-AoA, the RSRP measurements from gNBs may be gathered by LMF and then send to UE.

[0183] Referring to FIGS. **16-17**, in some designs, the position estimation entity may receive, from one or more base stations associated with the first and second measurements, beam squint related information, the positioning estimate of the UE is based in part on the beam squint related information. For example, for UE-assisted positioning, the position estimation entity may correspond to LMF and the beam squint related information may be sent via NRPPa signaling. In another example, for UE-based positioning, and the beam squint related information may be sent to the UE for position estimation. In some designs, the beam squint related information may include information related to an antenna layout, a number of antennas, a spacing between

antenna elements (e.g., defined with carrier frequency or absolute values), polarization, codebook, weight/phase of combiner, boresight of each beam of different CFs/BWPs, beamwidth of xdB (e.g., x=3 or 5 or 10, etc.) of different CFs/BWPs, and so on.

[0184] In the detailed description above it can be seen that different features are grouped together in examples. This manner of disclosure should not be understood as an intention that the example clauses have more features than are explicitly mentioned in each clause. Rather, the various aspects of the disclosure may include fewer than all features of an individual example clause disclosed. Therefore, the following clauses should hereby be deemed to be incorporated in the description, wherein each clause by itself can stand as a separate example. Although each dependent clause can refer in the clauses to a specific combination with one of the other clauses, the aspect(s) of that dependent clause are not limited to the specific combination. It will be appreciated that other example clauses can also include a combination of the dependent clause aspect(s) with the subject matter of any other dependent clause or independent clause or a combination of any feature with other dependent and independent clauses. The various aspects disclosed herein expressly include these combinations, unless it is explicitly expressed or can be readily inferred that a specific combination is not intended (e.g., contradictory aspects, such as defining an element as both an insulator and a conductor). Furthermore, it is also intended that aspects of a clause can be included in any other independent clause, even if the clause is not directly dependent on the independent clause.

[0185] Implementation examples are described in the following numbered clauses:

[0186] Clause 1. A method of operating a wireless node, comprising: performing a first measurement of a reference signal for positioning (RS-P) on a first sub-band of a plurality of sub-bands associated with an RS-P resource; performing a second measurement of the RS-P on a second sub-band of the plurality of sub-bands associated with the RS-P resource; and transmitting, to a position estimation entity in association with a positioning session of a user equipment (UE), a measurement report comprising a first indication of the first measurement and a second indication of the second measurement.

[0187] Clause 2. The method of clause 1, wherein the first and second sub-bands are separated in frequency by at least one intervening sub-band.

[0188] Clause 3. The method of any of clauses 1 to 2, wherein the first measurement, the second measurement, or both, comprise a reference signal received power (RSRP) measurement, a timing measurement, or a combination thereof.

[0189] Clause 4. The method of any of clauses 1 to 3, wherein the wireless node corresponds to a user equipment (UE).

[0190] Clause 5. The method of clause 4, wherein the positioning session is UE-assisted, and wherein the position estimation entity corresponds to a location management function (LMF).

[0191] Clause 6. The method of any of clauses 4 to 5, wherein the positioning session is UE-based such that the position estimation entity corresponds to the UE, and wherein the measurement report is transmitted via transfer between logical components of the UE.

[0192] Clause 7. The method of any of clauses 1 to 6, wherein the wireless node corresponds to a base station.

[0193] Clause 8. The method of clause 7, wherein the positioning session is UE-assisted, and wherein the position estimation entity corresponds to a location management function (LMF).

[0194] Clause 9. The method of any of clauses 1 to 8, wherein the position estimation entity corresponds to a user equipment (UE), a base station, a location management function, or a combination thereof.

[0195] Clause 10. The method of any of clauses 1 to 9, further comprising: receiving a report configuration associated with the measurement report.

[0196] Clause 11. The method of clause 10, wherein the report configuration indicates a list of sub-bands.

[0197] Clause 12. The method of clause 11, wherein each sub-band in the list of sub-bands is specified by: a start point of the RS-P resource, and an end-point of the RS-P resource, or a start point of the RS-P resource along with an offset, or a start point of the RS-P resource along with an absolute bandwidth (BW), or a start point of the RS-P resource along with an a BW relative to the RS-P, or a start tone and end tone, or a sub-band indicator associated with an indicator list of RS-P resources or RS-P blocks within stitched RS-P resources, or a sub-band indicator associated with an indicator list of sub-bands associated with New Radio Unlicensed (NRU) spectrum, or a number of sub-bands per RS-P, or a combination thereof.

[0198] Clause 13. The method of any of clauses 11 to 12, wherein the list of sub-bands comprises one or more recommended or non-recommended sub-bands for measurement, one or more requested or non-requested sub-bands for measurement, a priority or ranking of sub-bands for measurement within the list of sub-bands, or a combination thereof.

[0199] Clause 14. A method of operating a position estimation entity, comprising: receiving, from a wireless node in association with a positioning session of a user equipment (UE), a measurement report comprising a first indication of a first measurement of a reference signal for positioning (RS-P) on a first sub-band of a plurality of sub-bands associated with an RS-P resource, and a second indication of a second measurement of the RS-P on a second sub-band of the plurality of sub-bands associated with the RS-P resource; and determining a positioning estimate of the UE based in part on the measurement report.

[0200] Clause 15. The method of clause 14, further comprising: receiving, from one or more base stations associated with the first and second measurements, beam squint related information, wherein the positioning estimate of the UE is based in part on the beam squint related information.

[0201] Clause 16. The method of any of clauses 14 to 15, wherein the first and second sub-bands are separated in frequency by at least one intervening sub-band.

[0202] Clause 17. The method of any of clauses 14 to 16, wherein the first measurement, the second measurement, or both, comprise a reference signal received power (RSRP) measurement, a timing measurement, or a combination thereof.

[0203] Clause 18. The method of any of clauses 14 to 17, wherein the wireless node corresponds to a user equipment (UE).

[0204] Clause 19. The method of clause 18, wherein the positioning session is UE-assisted, and wherein the position estimation entity corresponds to a location management function (LMF).

[0205] Clause 20. The method of any of clauses 14 to 19, wherein the positioning session is UE-based such that the position estimation entity corresponds to the UE, and wherein the measurement report is received via transfer between logical components of the UE.

[0206] Clause 21. The method of any of clauses 14 to 20, wherein the wireless node corresponds to a base station.

[0207] Clause 22. The method of clause 21, wherein the positioning session is UE-assisted, and wherein the position estimation entity corresponds to a location management function (LMF).

[0208] Clause 23. The method of any of clauses 14 to 22, wherein the position estimation entity corresponds to a user equipment (UE), a base station, a location management function, or a combination thereof.

[0209] Clause 24. The method of any of clauses 14 to 23, further comprising: transmitting, to the wireless node, a report configuration associated with the measurement report.

[0210] Clause 25. The method of clause 24, wherein the report configuration indicates a list of sub-bands.

[0211] Clause 26. The method of clause 25, wherein each sub-band in the list of sub-bands is specified by: a start point of the RS-P resource and an end-point of the RS-P resource, or a start point of the RS-P resource along with an offset, or a start point of the RS-P resource along with an absolute bandwidth (BW), or a start point of the RS-P resource along with an a BW relative to the RS-P, or a start tone and end tone, or a sub-band indicator associated with an indicator list of RS-P resources or RS-P blocks within stitched RS-P resources, or a sub-band indicator associated with an indicator list of sub-bands associated with New Radio Unlicensed (NRU) spectrum, or a number of sub-bands per RS-P, or a combination thereof.

[0212] Clause 27. The method of any of clauses 25 to 26, wherein the list of sub-bands comprises one or more recommended or non-recommended sub-bands for measurement, one or more requested or non-requested sub-bands for measurement, a priority or ranking of sub-bands for measurement within the list of sub-bands, or a combination thereof.

[0213] Clause 28. An apparatus comprising a memory and at least one processor communicatively coupled to the memory, the memory and the at least one processor configured to perform a method according to any of clauses 1 to 27.

[0214] Clause 29. An apparatus comprising means for performing a method according to any of clauses 1 to 27.

[0215] Clause 30. A non-transitory computer-readable medium storing computer-executable instructions, the computer-executable comprising at least one instruction for causing a computer or processor to perform a method according to any of clauses 1 to 27.

[0216] Those of skill in the art will appreciate that information and signals may be represented using any of a variety of different technologies and techniques. For example, data, instructions, commands, information, signals, bits, symbols, and chips that may be referenced throughout the above description may be represented by voltages, currents, electromagnetic waves, magnetic fields or particles, optical fields or particles, or any combination thereof.

[0217] Further, those of skill in the art will appreciate that the various illustrative logical blocks, modules, circuits, and algorithm steps described in connection with the aspects disclosed herein may be implemented as electronic hardware, computer software, or combinations of both. To clearly illustrate this interchangeability of hardware and software, various illustrative components, blocks, modules, circuits, and steps have been described above generally in terms of their functionality. Whether such functionality is implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system. Skilled artisans may implement the described functionality in varying ways for each particular application, but such implementation decisions should not be interpreted as causing a departure from the scope of the present disclosure.

[0218] The various illustrative logical blocks, modules, and circuits described in connection with the aspects disclosed herein may be implemented or performed with a general purpose processor, a DSP, an ASIC, an FPGA, or other programmable logic device, discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions described herein. A general purpose processor may be a microprocessor, but in the alternative, the processor may be any conventional processor, controller, microcontroller, or state machine. A processor may also be implemented as a combination of computing devices, e.g., a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration.

[0219] The methods, sequences and/or algorithms described in connection with the aspects disclosed herein may be embodied directly in hardware, in a software module executed by a processor, or in a combination of the two. A software module may reside in random access memory (RAM), flash memory, read-only memory (ROM), erasable programmable ROM (EPROM), electrically erasable programmable ROM (EEPROM), registers, hard disk, a removable disk, a CD-ROM, or any other form of storage medium known in the art. An example storage medium is coupled to the processor such that the processor can read information from, and write information to, the storage medium. In the alternative, the storage medium may be integral to the processor. The processor and the storage medium may reside in an ASIC. The ASIC may reside in a user terminal (e.g., UE). In the alternative, the processor and the storage medium may reside as discrete components in a user terminal.

[0220] In one or more example aspects, the functions described may be implemented in hardware, software, firmware, or any combination thereof. If implemented in software, the functions may be stored on or transmitted over as one or more instructions or code on a computer-readable medium. Computer-readable media includes both computer storage media and communication media including any medium that facilitates transfer of a computer program from one place to another. A storage media may be any available media that can be accessed by a computer. By way of example, and not limitation, such computer-readable media can comprise RAM, ROM, EEPROM, CD-ROM or other optical disk storage, magnetic disk storage or other magnetic storage devices, or any other medium that can be used to carry or store desired program code in the form of instruc-

tions or data structures and that can be accessed by a computer. Also, any connection is properly termed a computer-readable medium. For example, if the software is transmitted from a website, server, or other remote source using a coaxial cable, fiber optic cable, twisted pair, digital subscriber line (DSL), or wireless technologies such as infrared, radio, and microwave, then the coaxial cable, fiber optic cable, twisted pair, DSL, or wireless technologies such as infrared, radio, and microwave are included in the definition of medium. Disk and disc, as used herein, includes compact disc (CD), laser disc, optical disc, digital versatile disc (DVD), floppy disk and Blu-ray disc where disks usually reproduce data magnetically, while discs reproduce data optically with lasers. Combinations of the above should also be included within the scope of computer-readable media.

[0221] While the foregoing disclosure shows illustrative aspects of the disclosure, it should be noted that various changes and modifications could be made herein without departing from the scope of the disclosure as defined by the appended claims. The functions, steps and/or actions of the method claims in accordance with the aspects of the disclosure described herein need not be performed in any particular order. Furthermore, although elements of the disclosure may be described or claimed in the singular, the plural is contemplated unless limitation to the singular is explicitly stated.

What is claimed is:

1. A method of operating a wireless node, comprising:

performing a first measurement of a reference signal for positioning (RS-P) on a first sub-band of a plurality of sub-bands associated with an RS-P resource;

performing a second measurement of the RS-P on a second sub-band of the plurality of sub-bands associated with the RS-P resource; and

transmitting, to a position estimation entity in association with a positioning session of a user equipment (UE), a measurement report comprising a first indication of the first measurement and a second indication of the second measurement.

2. The method of claim **1**, wherein the first and second sub-bands are separated in frequency by at least one intervening sub-band.

3. The method of claim **1**, wherein the first measurement, the second measurement, or both, comprise a reference signal received power (RSRP) measurement, a timing measurement, or a combination thereof.

4. The method of claim **1**,

wherein the positioning session is UE-assisted, and

wherein the position estimation entity corresponds to a location management function (LMF).

5. The method of claim **1**,

wherein the positioning session is UE-based such that the position estimation entity corresponds to the UE, and

wherein the measurement report is transmitted via transfer between logical components of the UE.

6. The method of claim **1**, wherein the position estimation entity corresponds to a user equipment (UE), a base station, a location management function, or a combination thereof.

7. The method of claim **1**, further comprising:

receiving a report configuration associated with the measurement report.

8. The method of claim **7**, wherein the report configuration indicates a list of sub-bands.

9. The method of claim **8**, wherein each sub-band in the list of sub-bands is specified by:

a start point of the RS-P resource, and an end-point of the RS-P resource, or

a start point of the RS-P resource along with an offset, or

a start point of the RS-P resource along with an absolute bandwidth (BW), or

a start point of the RS-P resource along with a BW relative to the RS-P, or

a start tone and end tone, or

a sub-band indicator associated with an indicator list of RS-P resources or RS-P blocks within stitched RS-P resources, or

a sub-band indicator associated with an indicator list of sub-bands associated with New Radio Unlicensed (NRU) spectrum, or

a number of sub-bands per RS-P, or

a combination thereof.

10. The method of claim **8**, wherein the list of sub-bands comprises one or more recommended or non-recommended sub-bands for measurement, one or more requested or non-requested sub-bands for measurement, a priority or ranking of sub-bands for measurement within the list of sub-bands, or a combination thereof.

11. A method of operating a position estimation entity, comprising:

receiving, from a wireless node in association with a positioning session of a user equipment (UE), a measurement report comprising a first indication of a first measurement of a reference signal for positioning (RS-P) on a first sub-band of a plurality of sub-bands associated with an RS-P resource, and a second indication of a second measurement of the RS-P on a second sub-band of the plurality of sub-bands associated with the RS-P resource; and

determining a positioning estimate of the UE based in part on the measurement report.

12. The method of claim **11**, further comprising:

receiving, from one or more base stations associated with the first and second measurements, beam squint related information,

wherein the positioning estimate of the UE is based in part on the beam squint related information.

13. The method of claim **11**, wherein the first and second sub-bands are separated in frequency by at least one intervening sub-band.

14. The method of claim **11**, wherein the first measurement, the second measurement, or both, comprise a reference signal received power (RSRP) measurement, a timing measurement, or a combination thereof.

15. The method of claim **11**,

wherein the positioning session is UE-assisted, and

wherein the position estimation entity corresponds to a location management function (LMF).

16. The method of claim **11**,

wherein the positioning session is UE-based such that the position estimation entity corresponds to the UE, and

wherein the measurement report is received via transfer between logical components of the UE.

17. The method of claim **11**, wherein the position estimation entity corresponds to a user equipment (UE), a base station, a location management function, or a combination thereof.

18. The method of claim **11**, further comprising:

transmitting, to the wireless node, a report configuration associated with the measurement report.

19. The method of claim **18**, wherein the report configuration indicates a list of sub-bands.

20. The method of claim **19**, wherein each sub-band in the list of sub-bands is specified by:

a start point of the RS-P resource and an end-point of the RS-P resource, or

a start point of the RS-P resource along with an offset, or

a start point of the RS-P resource along with an absolute bandwidth (BW), or

a start point of the RS-P resource along with a BW relative to the RS-P, or

a start tone and end tone, or

a sub-band indicator associated with an indicator list of RS-P resources or RS-P blocks within stitched RS-P resources, or

a sub-band indicator associated with an indicator list of sub-bands associated with New Radio Unlicensed (NRU) spectrum, or

a number of sub-bands per RS-P, or

a combination thereof.

21. The method of claim **19**, wherein the list of sub-bands comprises one or more recommended or non-recommended sub-bands for measurement, one or more requested or non-requested sub-bands for measurement, a priority or ranking of sub-bands for measurement within the list of sub-bands, or a combination thereof.

22. A wireless node, comprising:

a memory;

at least one transceiver; and

at least one processor communicatively coupled to the memory and the at least one transceiver, the at least one processor configured to:

perform, via the at least one transceiver, a first measurement of a reference signal for positioning (RS-P) on a first sub-band of a plurality of sub-bands associated with an RS-P resource;

perform, via the at least one transceiver, a second measurement of the RS-P on a second sub-band of the plurality of sub-bands associated with the RS-P resource; and

transmit, via the at least one transceiver to a position estimation entity in association with a positioning session of a user equipment (UE), a measurement report comprising a first indication of the first measurement and a second indication of the second measurement.

23. The wireless node of claim **22**, wherein the first and second sub-bands are separated in frequency by at least one intervening sub-band.

24. The wireless node of claim **22**, wherein the first measurement, the second measurement, or both, comprise a reference signal received power (RSRP) measurement, a timing measurement, or a combination thereof.

25. The wireless node of claim **22**, wherein the at least one processor is further configured to receive a report configuration associated with the measurement report.

26. The wireless node of claim **25**, wherein the report configuration indicates a list of sub-bands.

27. A position estimation entity, comprising:

a memory;

at least one transceiver; and

at least one processor communicatively coupled to the memory and the at least one transceiver, the at least one processor configured to:

receive, from a wireless node in association with a positioning session of a user equipment (UE), a measurement report comprising a first indication of a first measurement of a reference signal for positioning (RS-P) on a first sub-band of a plurality of sub-bands associated with an RS-P resource, and a second indication of a second measurement of the RS-P on a second sub-band of the plurality of sub-bands associated with the RS-P resource; and

determine a positioning estimate of the UE based in part on the measurement report.

28. The position estimation entity of claim **27**,

wherein the at least one processor is further configured to receive, from one or more base stations associated with the first and second measurements, beam squint related information,

wherein the positioning estimate of the UE is based in part on the beam squint related information.

29. The position estimation entity of claim **27**, wherein the first and second sub-bands are separated in frequency by at least one intervening sub-band.

30. The position estimation entity of claim **27**, wherein the first measurement, the second measurement, or both, comprise a reference signal received power (RSRP) measurement, a timing measurement, or a combination thereof.

* * * * *